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Three numbers of the Journal are published every year, in April, August and December respectively and contributions for publication should be sent to the Editor not later than February 1, June 1, and October 1 respectively.

Contributors are requested to be clear and concise. Manuscripts should not exceed 8,000 words and should be in a final form for the press. Each paper should start with a short summary which should be an abstract of the whole paper, complete and clear in itself, and not over 3 per cent. of the length of the paper. The introduction and reviews of literature should be restricted to closely pertinent papers.

The manuscript should be typewritten on one side of the paper only, with wide margins and be double spaced throughout including titles, footnotes, literature citations and legends. Symbols, formulae and equations must be written clearly and with great care. Scientific names of genera and species are printed in italics and should be underlined in the typescript. Too many tables, graphs, etc. should be avoided. Each table should be typed on a separate sheet with its proper position marked in the text in pencil.

Literature citations: All references to literature cited in the text should be presented together at the end of the paper in alphabetical order of authors' names. Each reference should be given in a standard form as follows: (1) name(s), followed by initial(s), of author(s); (2) year of publication in brackets; (3) full title of paper; (4) title of journal, abbreviated according to *World List of Scientific Periodicals*, 1952, and underlined; (5) volume number in Arabic numerals, underlined with two lines to indicate bold type; (6) page numbers without the prefix, p. When books are mentioned in the references, the order should be: name of author(s), initial(s), year in brackets, title of the book, which should be underlined, volume number, edition, page, followed by place of publication and name of publisher. Where a reference has not been seen in original, it should be indicated by an asterisk and the name of the abstracting journal or other source should be mentioned in brackets. If the title is in a language other than English, the diacretic signs, etc., should be precisely given as in the original.

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References:

Raman, C. V. (1949) The theory of the Christiansen experiment. *Proc. Indian Acad. Sci.* A 29: 381-90.

Sahni, B. (1936a) Wegener's theory of continental drift in the light of Palaeobotanical evidence. *J. Indian bot. Soc.* 15: 31-32.

Sahni, B. (1936b) The Karewas of Kashmir. *Curr. Sci.* 5: 10-16.

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A Contribution to the Life Histories and Feeding Habits of Horse-mackerels, *Megalaspis Cordyla* (Linn) and Caranx Mate (Curv and val) and Notes on the Effect of Absence of Light on the Development and Feeding Habits of Larvae and Post Larvae of *Megalaspis Cordyla* **

BY

DR. M. D. K. KUTHALINGAM*

(Madras University Zoology Research Laboratory)

(Received for publication on 2-5-1959)

ABSTRACT

A total number of 528 eggs of *Megalaspis cordyla* and *Caranx mate* were collected from the inshore plankton of the Madras coast. They were brought to the laboratory and reared upto identifiable juveniles. The various stages in life histories are described with observations on its food and feeding habits during the different stages of growth. Feeding begins invariably with the transformation of the pro larvae into post larvae. The early post larvae of *Megalaspis cordyla,* begins on a diet of copepod nauplii and diatoms but gradually changes over to larger pelagic organisms as it grows and finally subsists on planktonic as well as nectonic organisms; whereas on the other hand *Caranx mate* is a carnivore feeding chiefly on planktonic crustacea almost throughout its life though occasionally a stay adult may be found to have fed on numerous clupeids larvae where these occur plentifully in the surface waters. Therefore it will not be quite correct to describe *Caranx mate* as piscivorous or as a predator of crustacea. It was also recorded that while all other conditions were same in the case of development of eggs and larvae of *Megalaspis cordyla* the absence of light retarded the hatching by 26 hours and the pigmentation of the embryo disappeared

** Formed part of a thesis for the Degree of Doctor of Philosophy of the University of Madras.

* Present address: Central Marine Fisheries Research Station. Marine Fisheries P.O. Mandapam Camp. South India.

Introduction

Several authors have studied the feeding habits of adults of the Indian Horse mackerels; *Caranx nigresence* and *C. ciliaris* (Devanesan and Chidambaram 1948 and 1953), *C.hippos* and *C.sansusn* (Chacko 1949) and *Caranx djedaba* (Mahadevan 1950 and Kuthalingam 1955b). Their eggs and pro-larvae, however have been described only by Nair 1952) and Vijayarahavan (1953). These authors have referred the eggs they have described only to the genus; hence their descriptions have no specific accuracy. There has been no complete study of the life history of any one species including descriptions of eggs, post larvae and juveniles nor has the diet of the species during different stages been studied and compared with that of the adults.

Both the carangids *Megalaspis cordyla* and *C.mate* occur in the in-shore waters of Madras almost right through the year. Both the species are notable among the cheaper grade of fishes sold in the Madras markets; therefore a complete study of the life history and feeding habits of these species also will be of value. A note is added on the effect of lack of light on the rate of development.

Material and Method

A detailed account of the method of rearing the Marine fish eggs and larvae under the normal laboratory condition has been described by the authors elsewhere (1959a). Here in the present account a brief note on the method employed on the rearing and development of *M.cordyla* in complete darkness is given below.

Since the optimum temperature for development was 3° less than that of the laboratory (Laboratory temperature 31°C) nearly 237 eggs were reared in bowls of sea water immersed in water cooled by the addition of ice, kept in wooden box described before (1959a). The top of the box was of plate glass which could admit diffused light. This served as control. The 155 eggs used for the experiments were reared in the bowls left within a tin cooling chamber described earlier (loc. cit) and were darkened completely with thick black cloth. To ensure the complete exclusion of light this chamber was left in a dark room. In both the control and the experiment the larvae were taken out for brief periods for the purpose of examination. In the case of the experimented forms the larvae after examination were not put back.

Life History and Feeding Habits of Megalaspis Cordyla (Linn) (Caranx Rottleri Day)

Eggs:

239 eggs were collected from the in-shore plankton during the month of February, 1957. They were spherical and contained a single oil globule, as well as a yolk mass which was segmented. The egg had an average diameter of 0·9 mm. and was larger than that of *Caranx mate*. It differed also in being faint pale yellow in colour and having black pigment spots on the embryo and on the inner surface of all oil globule. The eyes and the auditory vesicles were also found and the heart was pulsating (Fig. 1). The embryo was well developed and made occasional twitching movements and the eggs were hatched about two hours after collection, i.e., about 12 noon.

Larvae just hatched (Fig. 2) :

All the 239 eggs were hatched into healthy larvae 1·9 mm. long. The yolk mass extended anteriorly beyond the head and the oil globule was situated posteriorly. The gut was short and extended close to the margin of the yolk sac and the anus opened beneath the 14th myotome. The pigmentation was the same as in the embryo though new black pigment cells were seen along the dorsal and ventral fin folds.

Larvae 20 hours after hatching (Fig. 3) :

Over-night six larvae out of 239 larvae died. Considerable increase in length was noticed and the larvae now measured 2·3 mm. The yolk was much reduced and the oil globule remained unabsorbed. There was no reduction in the number of pre-anal myotomes; on the other hand ten post-anal myotomes could be counted at this stage. The rudiment of the pectoral fin had developed under the fourth myotome. Yellow pigment cells were seen in the 6th, 8th, and 10th myotomes and towards the end of the tail region in addition to the black pigment cells which remained same as in the previous stage.

Towards evening, i.e., about 3 p.m., the larvae had increased in length by 0·1 mm. and measured 2·4 mm. The larvae retained the oil globule though the yolk was much reduced (Fig. 4). The black pighent cells remained the same whereas the yellow pigment cells were seen in the 15th, 18th and 20th myotomes in addition to the previous ones. Rudiments of pectoral fins were seen.

Larvae 48 hours after hatching (Fig. 5) :

The larvae had grown slightly and measured 2·6 mm. in length. The yolk was much reduced in size and the gut was clearly visible and was in communication with the recently formed mouth. 2 or 3 gills could be faintly seen and the jaws were movably articulated. There was no change in the number of pre-anal myotomes but post-anal myotomes had increased to nineteen. The pectoral fin had grown in size and developed fin-rays while the other fins were in the fin-fold stage and devoid of rays. The pigmentation remained as before.

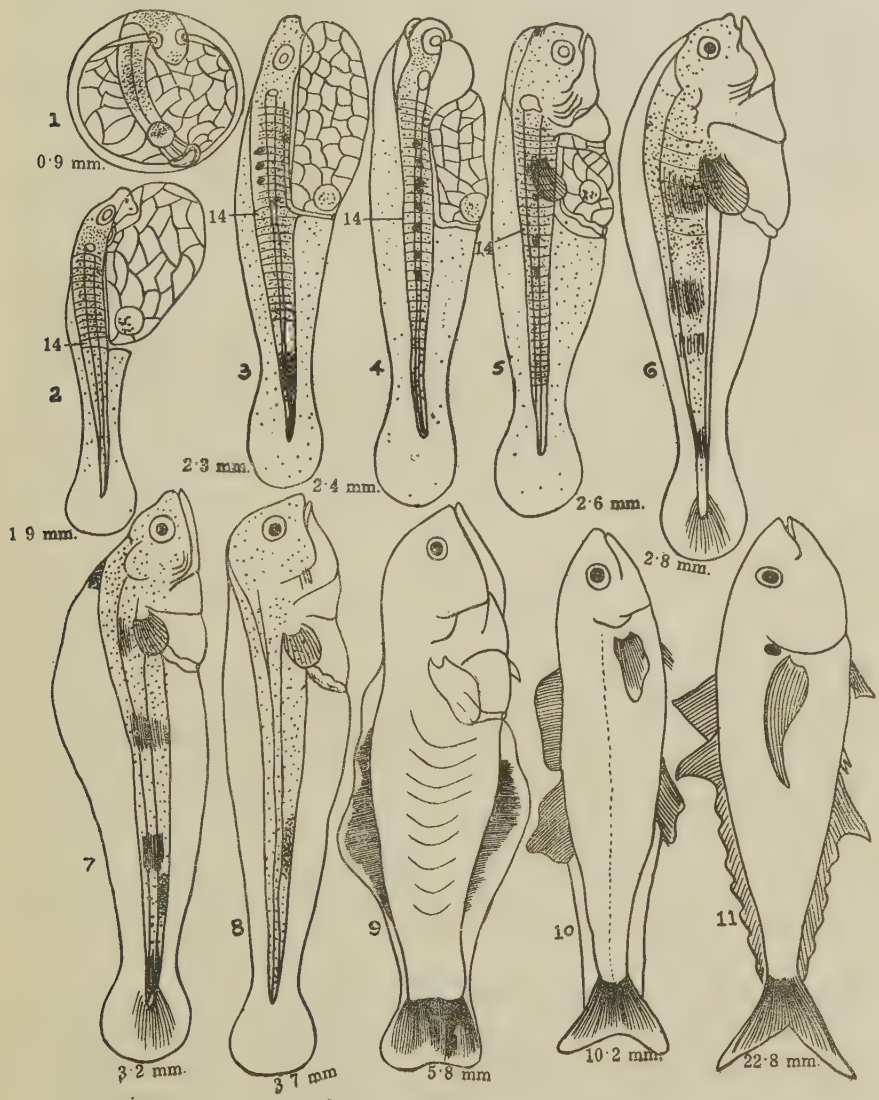
Larvae 54 hours after hatching (Fig. 6) :

By the evening of the third day after hatching, twenty-one larvae died since they were passing through the critical period becoming transformed into the post-larvae. The oil globule and the yolk had been completely absorbed and the post-larvae were now resting at the bottom of the glass containers. The larvae were now 2·8 mm. in length and the mouth was well developed with prominent jaws. The iris was pigmented and the black pigment cells formed on the dorsal and ventral fin-folds in the previous stage had disappeared completely. The yellow pigment cells which were found here and there were united to form four patches of cells on each side of the body. Black pigment cells scattered all over the body had multiplied to such an extent that it was with difficulty that the pre-anal myotomes could be counted. Different articles of food collected from the plankton, copepod nauplii, adult copepods of *Macrosetella gracilis, Oithona sp, Euterpina sp, Paracalanus parvus, Pseudodiaptomus sp,* nauplii of *Balanus amphitrite,* chopped bits of polychaetes larvae, larval bivalves, and diatoms were supplied to the post-larvae which accepted copepod nauplii and diatoms, and rejected the other food articles.

Larvae 4th day after hatching (Fig. 7) :

Though the larvae had grown to 3·2 mm. in length they appeared very much changed. The anterior myotomes of the trunk had increased in height, and the lower jaw had become very conspicuous. The pectoral fins were semi-circular flaps with fin-rays, the caudal fin also developed fin-rays and the median fins were still in the fin-fold stage. A few black branching chromatophores were present at the base of the dorsal fin-fold towards the head region and also at the ventral margin of the myotomes about

half the distance between the vent and the tip of the tail. The rest of the pigmentation remained as in the previous stage.



Text-Figs. 1-11. *Megalaspis Cordyla*

No change in structure or feeding was noticed for another two days.

Lvrvae 7th day after hatching (Fig. 8) :

The post-larvae attained a length of 3·7 mm. The yellow patches of pigmentation as well as the black pigment cells on the top of the head disappeared.

There was no change in the structure and feeding for another two days.

Larvae 10th day after hatching (Fig. 9) :

The larvae had increased in length and measured 5·8 mm. There was also an increase in height of the body owing to the increase in height of the myotomes whose number however remained the same. Owing to the body having become opaque and the skin becoming pigmented, the myotomes could be distinguished only after staining and clearing in cedar wood oil. The incipient elements of the operculum extended down and almost hid the lower jaw when it closed. The fin rays of the ventral fin were beginning to appear from the anterior border of the ventral margin backwards. Similarly a number of soft rays arose in the region of the dorsal fin.

There was no change in feeding during the next eight days.

Different groups of post-larvae were supplied with molluscan larvae, eggs of *Neptunus sanguinolentus,* polychaete larvae, copepod nauplii, cirripede larvae, adult copepods such as *Oithona* sp, *Euterpina* sp, *Temora* sp, and *Acartia* sp, diatoms such as *Coscinodiscus* sp, *Asterionella* sp, and *Trichodesmium* sp, and unsorted plankton. It was found that the post-larvae at this stage fed on nauplii of copepods and cirripedes, whereas diatoms were totally rejected. This observation was confirmed by further experiments on larvae supplied only with the particular items of food and counting the food organisms supplied and left behind.

Larvae 19th day after hatching (Fig. 10) :

The post-larvae now measured 10·2 mm. in length. Though the general shape of the body was characteristic of the post-larvae, yet the unpaired fins and the newly acquired lateral line were distinctly juvenile features foreshadowing those of the adult. Though the pigmentation had disappeared from the rest of the body, it remained the same as before in the region of the abdomen. Jaws were still toothless. Fin-rays were more clearly visible in the pectoral, anterior dorsal, posterior dorsal, pelvic and caudal fins.

The caudal fin showed signs of becoming forked. All the fins were still transparent.

No change was oberved in feeding for another thirteen days.

Adult copepods such as *Paracalanus parvus, Oithona sp., Pseudodiaptomus sp., Temora sp., Acartia sp.,* and *Euterpina sp.,* formed the principal items of food while small quantities of megalopa larvae, *Lucifer sp.,* and *Sagitta sp.,* were also found in the stomachs of fishes.

Larvae 33rd day after hatching (Fig. 11) :

The length averaged to 22·8 mm. Almost all the features of the juvenile stage had developed during the interval of thirteen days. The cleft of the mouth was very slightly oblique and the lower jaws was slightly longer. Teeth were present on both the jaws. A large black spot appeared on the upper and posterior portion of the opercle. The ventral side of the body was silvery with a metallic blue. The opercle was clearly seen but without the denticulations present in the adults. The body was covered by a thin whitish and shining skin. The following fin formula could be made out at this stage: — D.8 | 1/10. A.2 | 1/9. C.18, and the fish could be identified as *Megalaspis cordyla.*

It was seen here that the species of *M. cordyla* feed on a large variety of planktonic animals such as copepods (*Macrosetella gracilis, Oithona* sp., *Euterpina* sp., *Paracalanus* sp. *Pseudodiaptomus* sp., and *Acartia* sp.), nauplii of *Balanus amphitraita,* larval bivalves, larval polychaetes, *Lucifer* sp., Pluteus larvae and a few dinoflagellates (*Ceratium* sp., and *Peridinium* sp.).

Diet of adults in in-shore waters of Madras :

Adolescent forms and immature adult fishes measuring 142-162 mm. caught between the months of July and November appear to have fed voraciously on a variety of pelagic animals. Although still as in the juvenile stages crustacea constituted a major portion of the diet, copepods (*paracalanus* sp., *Temora* sp., *Pseudodiaptomus* sp., *Oithona rigida, Acartia* sp. and *Euterpina* sp.), *Acetes* sp., *Squilla* larvae, and *Penaeus* larvae and *Lucifer* were the principal items of food while megalopa, *Mysis,* ostracoda, cirripede nauplii, molluscan larvae, polychaetes, *Sagitta* sp., and a few diatoms (*Coscinodiscus* sp., *Rhizosolenia* sp. and *Trichodesmium* sp., formed the minor items of the menu.

Adults measuring 188 mm.-220 mm. were caught in large numbers during December, January and February. These appeared to be only mature adults as well as spawners. The stomach contents of 118 of the former and 170 of the latter were examined. The diet of the two types did not differ and consisted of megalopa larvae, *Penaeus* sp., and *Metapenaeus* sp. larvae, nauplii and adult of copepods (*Pseudodiaptomus* sp., *Temora* sp., *Acartia* sp., *Paracalanus* sp., *Eucalanus* sp. and *Corycaeus* sp.), larval stages of *Acetes* sp., megalopa larvae, *Sagitta* sp., cypris larvae of *Balanus* sp. and *Gammarus* spp., teleosten eggs and larvae (clupeiods), cirripede nauplii, ostracoda, Mysis, zoea, and diatoms (*Coscinodiscus* sp., *Rhizosolenia* sp., *Planktonella* sp., *Fragilaria* sp., *Trichodesmium* sp.).

Diet of the adult in the off-shore:

From March to June this fish was totally absent from the in-shore waters though large numbers were landed from the off-shore area. 154 adults examined during this period from the off-shore nets show that they were mostly spent fishes suggesting that the spawners had migrated from the in-shore area since February. The diet consisted of such forms as were abundant in the off-shore area; adult teleosteans (*Lactarius* sp., *Caranx* sp., *Lates* sp., *Leiognathus* sp. and *Engraulis* sp.) and crustacea (*Penaeus* sp. and *Metapenaeus*) formed the main items. The rest of the diet was made up of *Sepia, Acetes* spp., Mysids like *Mesopodopsis* spp., copepods (*Temora* sp., *Acrocalanus* sp. and *Oithona* sp.), *Squilla* spp., ostracods and Cypris larvae. Diatoms occurred in a negigible quantity.

The data regarding the diet of the adults during the different months of the year are presented in Table (No. 1) to facilitate a few general inferences.

Remarks:

From the data collected and presented above it will be obvious that the adolescent and immature fishes arrive in the Madras in-shore waters in July and become mature and breed by February. Since the mature adults, breeders, adolescent and immature fishes were caught in this area and since the stomach contents examined showed that they had fed on a large variety of planktonic food, it may be inferred that the migration is for the purpose of feeding as well as for spawning. After February not only the adults but also the young forms were not landed throughout the Madras coast.

Table (No. 1) *showing the food items in the adolescent, immature, mature, spawners and spent fishes from the in-shore and off-shore regions in the different months*

Months	Location	Number of fishes examined	Gonadial condition of fish	Percentage	Diet	Percentage	Diet
July	I			16·8	Copepods	15·8	*Acetes sp*
	N	149		6.2	*Megalopa*	12·8	*Lucifer*
to	S		Adolescent	11·2	*Squilla sp*	10·2	*Penaeus sp*
	H	219		3·4	Mysis	4·3	Ostracoda
November	O		Immature	5·2	Cirripede nauplii	2·8	Polychaete
	R						larvae
	E			3·7	Molluscan larvae	4·6	*Sagitta sp*
December				3·0	diatoms		
	I			15·2	Copepods	12·2	Larval acetes
to	N			8·4	Cypris larvae	12·2	*Penaeus sp*
	S	118	Mature	6·0	Fish eggs and larvae	10·7	*Sagitta sp*
February	H			5·0	Copepod nauplii	4·2	Cirripede
	O		Spawners	4·2	Ostrocoda	4·2	nauplii
	R	170					diatoms
	E			4·4	Algae	5·1	Megalopa
				6·1	Zoea	2·1	*Mysis*
March	O			16·7	*Lactarius sp*	14·8	*Caranx sp*
	F			12·9	*Lates sp*	11·4	*Leiognathus sp*
to	F			10·7	*Penaeus sp*	8·9	*Engraulis sp*
	S	154	Spent	5·4	*Metapenaeus sp*	4·7	*Sepia sp*
June	H			4·6	*Acetes sp*	3·2	Mysis
	O			2·4	Copepods	1·2	Octracods
	R			3·1	Cypris larvae		
	E						

A large number of spent fishes were caught in off-shore waters about 20 miles away from the coast and the spent fishes were found to have fed on a larger prey like *Acetes, Squilla, Panaeus,* etc., voraciously, and it may be inferred that their migration is for feeding purpose.

Further, at any part of the year, i.e., whenever and wherever they are netted, the number landed show that they do not move in shoals even when they migrate for spawning and feeding purposes. Seasonal changes in the feeding habits correlated with migratory habits of the Mackerel (*Scomber scomber*) have been observed by Bullen (1912).

Larvae reared in darkness:

155 eggs were left in bowls of sea water in a dark-room. They were periodically examined (once taken out, the larvae were not replaced) and the progress of development was compared with that of the 239 eggs reared in light which served as a control. It was found that while all other conditions were same, the absence of light retarded the hatching by 26 hours and the pigmentation of the embryo disappeared. The pro-larvae which finally hatched measured 1·6 mm. and was 0·3 mm. shorter than the post-larvae of the control. The auditory vesicles were not in evidence as also the post-anal myotomes. The pro-larvae finally assumed the features of the post-larvae 96 hours after the commencement of the experiment, i.e., 70 hours after hatching, whereas in the control the post-larval stage was reached 52 hours after hatching.

The post-larvae measured only 2·4 mm. and did not have any pigmentation. Feeding experiments showed that these larvae reared in darkness fed only on diatoms and avoided all animal food. All these post-larvae died within 20 hours. Fresh eggs collected and reared in darkness confirmed the previous observation and when the post-larval stage was reached, half the number were left in an illuminated place. These developed pigment and changed over to the normal diet of the control (in about two days) whereas those in the darnkess died.

Since the effect of light on the development of tropical fishes has not been studied, the author is pursuing this investigation with reference to other species of fishes also and hopes to present the data later in a separate paper.

The life history and feeding habits of Caranx (selar) mate cuv and Val (Caranx affinis Day)

Eggs:

289 eggs of *Caranx mate* were collected from the plankton samples brought to the laboratory during the month of October. The eggs were perfectly spherical having an average diameter of 0·8 mm. and had an oil globule. The yolk was segmented showing large vacuoles, the segments being largest in the centre with the rudiment of the embryo visible and the surface of the oil globule showing black pigment spots (Fig. 12). The eggs which were brought to the laboratory at 10 a.m. became more irregular in shape with the rapid development of the embryo. At 12 noon the tail of the embryo became free from the yolk mass and began to show twitching movements. The head however was not free from the yolk. The segmentation of the yolk became faint and the oil globule shifted to the tail end of the embryo. The eyes and the auditory vesicle became distinct as also a functional heart. The black pigment spots on the embryo and on the inner surface of the oil globule became prominent, while numerous very faint pale yellow pigment cells also became apparent (Fig. 13). At 4-30 p.m. all the eggs hatched except 51.

Larvae just hatched (Fig. 14):

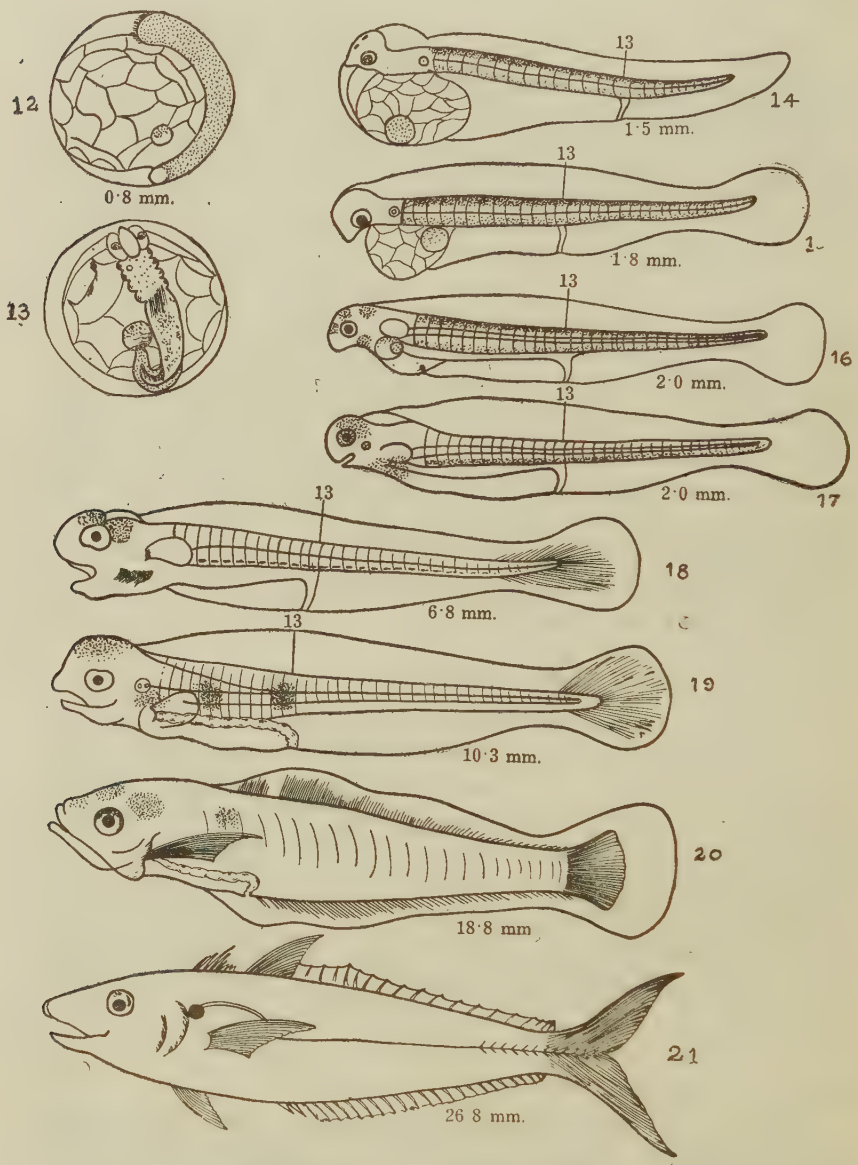
The larvae measured 1·5 mm. The segmentation of the yolk mass was faintly visible and the oil globule was situated in the posterior part of the yolk whereas in *Caranx trachurus* Delsman (1926) found it in the "anterior part of the yolk reaching the front of the head". There was no indication of the formation of the mouth or pectoral fins. Thirteen myotomes were noticed between the auditory vesicle and the anus. The disposition of the yellow pigment cells was the same as in the embryo while the black cells were mostly arranged along the dorsal side of the myotomes.

Larvae 24 hours old (Fig. 15):

The one day old larvae measured 1·8 mm. The yolk was reduced and the oil globule remained unabsorbed. The auditory vesicle was clearly seen. The head was very prominent and freed from the yolk. The yellow pigment cells had disappeared and the black pigmentation was the same as in the former stage.

Larvae 48 hours after hatching (Fig. 16):

The yolk mass had diminished in size, considerably, but the oil globule persisted and was smaller in size. The pectoral fin was



Text-Figs. 12-21. *Caranx Mate*

well formed but there was as yet no indication of the formation of the mouth. The larvae had grown slightly in length and

measured 2·0 mm. There were thirteen pre-anal and fourteen post-anal myotomes. The black pigment cells were distributed in the body as in the previous stage, but four patches of black pigment cells appeared near the head region.

Larvae 72 hours after hatching (Fig. 17):

On the morning of the fourth day after hatching, there was no increase in length; though the mouth had formed and opened into the alimentary canal the eyes were pigmented and the auditory vesicle and the pectoral fin had grown larger in size. The black pigmentation was restricted to the ventral side of the myotome and the four black patches near the head became crowded and formed a single mass. The yolk which was present in the morning was completely absorbed by 4 p.m. and in its position was indicated by a few black chromatophores which were formerly present on the yolk mass and the pro-larvae had become transformed into post-larvae. They were moving about vigorously inside the glass container.

Copepods (eggs, naupalii and adults), cirripede larvae, larval polychaetes, molluscan larvae, diatoms, algae and fish eggs collected from the plankton were introduced in the container. Four hours afterwards the guts of these post-larvae were examined. It was found that a large number of copepod nauplii had been eaten. In one or two post-larvae, cirripede and molluscan larvae were also found. To verify the nature of the diet twenty post-larvae were later supplied with nauplii and adults of copepods such as *Euterpina* sp., *Acartia* sp., and *Paracalanus* sp. Only the copepod nauplii were consumed. It is probable that adults were avoided because the post-larvae themselves measured only 2·0 mm. Another lot of fifty post-larvae were supplied with unsorted plankton and the examination of the gut contents showed that they also fed on large quantities of copepod nauplii and a few molluscan larvae. When fifty other post-larvae were supplied with fresh algae and diatoms mixed with copepod nauplii, larval molluscs, larval polychaetes and cirrepede larvae, and examined after four hours it was found that the larvae were decidedly carnivorous and restricted their diet to only copepod nauplii and larval mollusca.

Excepting for very gradual increase in length there was no change for another eight days.

Larvae 13th day after hatching (Fig. 18):

Twenty-eight larvae died during the preceding eight days. Though the post-larvae had increased to 6·8 mm. in length, the pectoral fins were still devoid of rays and there was no indication of the ventral fin. The fin-rays became apparent in the caudal region. The black cromatophores were arranged in broken chains along the ventral side of the myotome and the black patches of pigment were present in front of the eye.

The larvae continued to feed only on copepod nauplii and did not show any change in structure or diet for another four days.

Larvae 18th day after hatching (Fig. 19):

All the 210 larvae survived. The larvae had grown to a length of 10·3 mm. Though the pectoral fins had increased in size yet they were devoid of rays. The lower jaw was very conspicuous and the myotomes appeared slightly broadened dorso-ventrally. Patches of black pigment cells were seen scattered near the pectoral fin, above the anus, and above the eye. There was no other pigmentation. The alimentary canal was well marked and folds of the internal epithilium were seen towards the rectum. The pre-anal myotomes continued to be thirteen in number.

The larvae fed exclusively on copepod nauplii for another eight days.

Larvae 27th day after hatching (Fig. 20):

The post-larvae had attained a length of 18·8 mm. and the width of the body became a fourth of its total length; the larvae appeared very much changed in appearance. The pigment cells of the post-larvae were more widely distributed in the region of the head. Incipient elements of operculum had developed, the body was almost opaque and the myotomes which were clearly seen in the earlier stages were now only faintly visible. Caudal fin appeared slightly harder than the tissues around and find-rays could be detected in the anal fin-folds also. The pelvic fins had appeared. The dorsal and pectoral fins resembled those of the adults in shape, but were soft. Eyes had become black.

Feeding experiments performed on the twenty-seventh day showed that the larvae were able to take adult copepods of the genus *Oithona* sp., *Euterpina* sp., *Acartia* sp. and *Paracalanus* sp., and molluscan larvae. This change in diet is obviously related to the increase in size. The larval forms of polychaetes, cirripede

larvae, copepod nauplii, algae and diatoms were avoided. Seventy-eight larvae were killed during the course of this period for experiments on feeding.

The larvae grew in size but there was no change in general shape and appearance for another ten days.

Larvae 38th day after hatching (Fig. 21):

The larvae were now 26·8 mm. long, and had become juvenile fish with the body contour characteristic of the species. All the taxonomic features were in evidence and the fish could be identified as *Caranx mate* (D. 8.1/24. P. 24. A. 2.1/20. V. 6).

Out of 132 juveniles reared in the laboratory for thirty-eight days since hatching, sixty-four died on the 38th day morning owing to some reason.

Feeding experiments were conducted with the remaining sixty-eight specimens during the next four days. They were supplied with concentrated samples of fresh plankton. Since the juveniles were opaque several lots of them had to be killed from time to time in order to examine their stomach contents. Microscopic examination of the gut contents showed that the diet included several copepods (*Euterpina* sp., *Paracalanus parvus, Oithona rigida, Oithona spinulosa, Pseudodiaptomus* sp., *Corycaeus* sp., *Acartia erythraea, Temora* sp., *Labidocera* sp., *Centropages tenuiremis,* and *Schmackeria*). Molluscan larvae, young prawn larvae, penaeid and brachyuran larvae, *Lucifer* and amphipods were found but in fewer numbers. There was sufficient evidence to show that the juveniles fed voraciously and were strictly carnivorous. However since vegetable matter may be quickly digested and may be missed in a post mortem examination, one lot of juveniles were given only algae and diatoms, and examined after two hours. There was no vegetable matter in their guts. Another lot of juveniles were supplied with fish eggs and pro-larvae and copepods collected from the plankton. The stomach contents showed that the juveniles preferred to feed only on copepods. As all the juveniles reared for 42 days in the laboratory after hatching were killed for the above experiment, sixty-nine juveniles ranging between 20·5 mm.-29·5 mm. long were collected from the fishermen's net as well as from the plankton during the months of January and February for further observation. The lower jaw was slightly longer and they had villiform teeth arranged

in V shaped manner. The fourth dorsal spine was noticed to be the longest. The caudal fin was deeply forked. The fish was silvery along the back and golden on the abdomen. A black shoulder spot extending to the opercle described by Day (1889) was present. All the fins were yellow and the anals were edged with white. The tip of the second dorsal fin was white.

The analysis of the stomach contents showed that in these juveniles collected from the sea 70% of the food was copepods and the rest consisted of gastropod and bivalves larvae. Eighteen juveniles were found stuffed with only copepods such as *Euterpina* sp., *Acartia* sp., *Oithona* sp., *Paracalanus* sp., and *Corycaeus* sp.

Feeding habits of adults:

A study of sixty-two adults measuring 140 mm. to 160·5 mm. collected during the months of October, November and December showed them to be immature. Except four, all had food in the stomach. Analysis showed that *Squilla holoschista, Squilla mantis, Acetes erythraeus, Penaeus indicus* and *Penaeus carinatus* formed the major items of diet. Copepods and Amphipods were also found. The stomach of only one fish was exclusively filled with remains of fish (clupeids). Since they were in an advanced state of digestion, no specific identification could be made.

Remarks:

From the foregoing account of the food of *Caranx mate* it would appear that the diet of this species of Indian Horse-mackerel is not very different from that of the British species. Lebour (1919-'22) found that the post-larvae of *Caranx trachurus* subsists on copepods alone adding molluscan larvae to their menu only during the juvenile stage. In the present tropical form this addition of molluscs to a diet of copepods is anticipated even on the fourth day after hatching when the fish became post-larvae.

Though the information available regarding the diet of five of the ten Indian species of *Caranx*, point to a carnivorous type of feeding, yet it is evident that the five species differ in their selective tastes. Devanesan and Chidambaram (1948) have described *C. nigresence* and *C. ciliaris* as drift feeding carnivores, while Chacko (1949) is of opinion that *C. hippos* and *C. sansusn* are exclusively piscivorous, feeding in surface and midwaters. The present study shows that *Caranx mate* is a carnivore feeding chiefly

on plnktonic crustacea almost throughout its life though occasionally a stray adult may be found to have fed on numerous clupeid larvae when these occur plentifully in the surface waters. Therefore it will not be quite correct to describe *C. mate* as piscivorous or as a predator of crustacea.

Summary

1. Previous work on the life histories of Caranx, the feeding habits of larvae and juveniles is briefly reviewed.

2. Detailed account of the life histories with description of eggs just hatched-larvae and juveniles of *Megalaspis cordyla* and *Caranx mate* is given.

3. The composition of the earliest diet of the post larvae, the later changes in diet during the subsequent stages are described fully on the basis of experiments conducted on their feeding. The data gathered regarding their larval diet are compared with those of the adult diet.

4. Selective feeding, feeding migrations and vertical migrations during the life histories of *Megalaspis cordyla* and *C. mate* studied are commentated on wherever necessary. Inferences are drawn from analysis of diet, regarding any harmful effect on local fisheries.

5. Preliminary observations on the effect of absence of light on the development of eggs, larvae and juveniles of *M. cordyla* are made at the end of the life history of *Megalaspis cordyla.*

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Liquid-Liquid Extraction: Fractionation of Castor Oil Methyl Esters by Nitromethane and Cyclohexane

BY

C. M. Lakshmanan and G. S. Laddha

(*Alagappa Chettiar College of Technology, University of Madras*)

ABSTRACT

The methyl esters obtained by the methylation of castor oil have been fractionated to get fractions richer in methyl ricinoleate by means of liquid-liquid extraction using the pair of solvents, nitromethane and cyclohexane. In the present paper equilibrium solubility and phase distribution data are presented for the system castor oil methyl esters-nitromethane-cyclohexane at 30°C. The study indicates that nitromethane has a great affinity for the extraction of hydroxy esters from the castor oil methyl esters.

INTRODUCTION

One of the most commonly used vegetable oils, castor oil, differs from others in that it contains a hydroxy group in addition to an olefinic linkage in its predominating fatty acid, namely ricinoleic acid otherwise called as 12-hydroxy $\triangle^{9,10}$—octa decenoic acid. The analysis of fatty acid composition of castor oil (1956) shows that ricinoleic acid is present from 86 to 94%. The presence of hydroxyl group in the ricinoleic acid makes the acid and its derivatives useful for the manufacture of surface active agents, plasticizers and lubricating oil additives as well as for the production of chemicals such as sebacic acid, methyl-n-hexyl ketone, capryl alcohol, 10-undecylenic acid and heptaldehyde. The other hydroxy acid present in castor oil is dihydroxy stearic acid which is usually present upto 2%. Because of the high recinoleic acid content castor oil itself is used for many purposes in the place of ricinoleic acid. With the increased demand for ricinoleic acid and its derivatives, it is desirable to remove other fatty acids, especially nonhydroxy acids, so as to have the purest possible starting material.

Numerous methods such as distillation, fractional crystallisation, solvent extraction of castor oil fatty acids or its derivatives have been used for the fractionation of castor oil fatty acids. But

most of these methods are tedious and time taking. In order to meet the growing demand for ricinoleic acid and its derivatives of the purest form possible, an easy and convenient method based on liquid-liquid extraction of castor oil methyl esters was suggested by McCormack and Bolley (1954). The method is based on the observation that the compounds are most soluble in solvents which they resemble structurally. Thus the hydroxylated compounds, methyl ricinoleate and methyl dihydroxy stearate, would be preferentially distributed in the polar solvent in a polar solvent-castor oil methyl esters-nonpolar solvent system and the non hydroxylated compounds would appear chiefly in the non polar solvent phase. McCormack and Bolley (1954) took methanol as polar solvent and heptane as non polar solvent and studied the equilibrium solubility and distribution data at 8·4°C and 24°C. Later Kasturirangan and Laddha (1955) studied the system castor oil methyl esters- furfural-cyclohexane at 30°C. These studies indicated that the hydroxyl value of the fractionated esters from methanol and furfural phases were greater than that of esters from hydrocarbon phase. In the present work nitromethane is used as polar solvent and cyclohexane as non polar solvent. Mutual solubility and phase distribution data for the system castor oil methyl esters-nitromethane-cyclohexane at 30°C are presented.

Experimental

Materials Used:

1. Castor Oil Methyl esters: These were prepared by methylation of castor oil as suggested by Brown and Grean (1940). About 200 gms. of castor oil were mixed with 300 ml. of rectified methanol containing 2% dry hydrogen chloride and the mixture was refluxed for 24 hours. The excess of methanol was then partially recovered by distillation. The residue was cooled to room temperature, diluted with water and extracted with 500 ml. of ether. The extract in ether was washed until all the HCl was removed. The extract was then dried with anhydrous sodium sulphate and the ether was distilled off. The last traces of ether were removed by heating the esters under vacuum on a water bath. The mixed esters thus obtained had the following physical and chemical constants: density $d^{30°}_4$ 0·9250, refractive index at 30°C 1·4602, specific rotation $[\alpha]^{30°}_0$ + 5·4 saponification value 183·1, iodine value (Wij's, 30 mins., 31°C) 82·8, and hydroxyl value 165·75.

2. Nitromethane: Nitromethane was supplied by Fluka AG. Chemische Fabrik Bushs SG. (Switzerland). It was distilled over a rectification column and the fraction between 100·5—101·5°C was collected. The specification were, density $d^{30°}_4$ 1·1237 and refractive index at 30°C 1·3770.

3. Cyclohexane: Laboratory reagent grade cyclohexane supplied by B.D.H. Ltd., was rectified and fraction obtained between 80·5—81·5°C was collected and used. The specifications were density d^{30}_4 0·7725 and refractive index at 30°C 1·4206.

Experimental Procedure:

The limiting solubility and the tie lines in the ternary system at 30°C were determined by the method described by Othmer et al (1941). Known mixtures of methyl esters and nitromethane or methyl esters and cyclohexane were held in a water bath at 30° ± 1°C and were titrated with the third component until a turbidity appeared indicating the limiting solubility. For determining the phase distribution data, known mixtures of ternary constituents comprising of castor oil methyl esters, nitromethane and cyclohexane well within the heterogenous region were placed in the constant temperature bath after vigorous agitation and allowed to attain the equilibrium. The two phases formed were then separated and weighed. The amount of methyl esters distributed in each phase was determined by taking a weighed quantity of each phase and distilling off the solvents on a water bath. The last traces of solvents remaining were removed under vacuum by drying the esters on water bath to constant weight under a stream of carbon dioxide. The total weight of the esters thus obtained from the two phases was checked against the weight of esters taken originally in the mixture. The fractions of methyl esters obtained from each phase were evaluated in terms of their hydroxyl values by following the pyridine-acetic anhydride method of Burton and Robertshaw (1939).

RESULTS

The equilibrium solubility and phase distribution data along with the hydroxyl value of methyl esters distributed in the nitromethane and cyclohexane phases are given in Tables I and II respectively. These data are plotted on conventional triangular diagram in Fig. I. Here castor oil methyl esters are considered to be a single component, even though they are mixture of high molecular weight esters. In Fig. 2 weight percentage of methyl

TABLE I

Equilibrium Solubility Data at 30°C for the System Castor Oil Methyl Esters-Nitromethane-Cyclohexane

Weight Percent Composition of Liquids					
Methyl esters	Nitro-methane	Cyclo-hexane	Methyl esters	Nitro-methane	Cyclo-hexane
0·0	94·57	5·43	40·76	32·85	26·38
4·96	88·57	6·47	40·23	27·36	32·41
15·60	77·78	6·62	37·55	22·11	40·34
20·70	71·08	8·22	35·32	18·72	45·96
24·56	65·39	10·05	25·69	10·31	64·00
27·55	60·44	12·01	15·08	7·04	77·89
31·39	55·43	13·17	5·02	4·31	90·67
38·47	41·71	19·82	0·00	3·92	96·08

TABLE II

Equilibrium Tie Line Data at 30°C for the System Castor Oil Methyl Esters-Nitromethane-Cyclohexane

Esters	Composition of mixture taken		Weight percent of esters in		Hydroxyl values of esters	
	Nitromethane	Cyclohexane	Nitromethane phase	Cyclohexane phase	Nitromethane phase	Cyclohexane phase
5·10	50·05	39·85	2·98	8·19	198·6	148·3
10·35	45·27	44·38	4·47	15·32	188·6	159·2
14·68	55·18	30·14	6·32	25·92	186·3	155·1
14·99	62·13	22·88	6·69	31·14	186·3	154·6
20·49	54·71	24·79	8·06	35·35	185·0	157·4
20·33	59·66	20·01	8·89	38·02	184·7	156·6
25·05	54·91	20·04	10·37	39·84	179·9	158·5
28·41	54·85	16·76	14·51	39·57	175·1	163·7

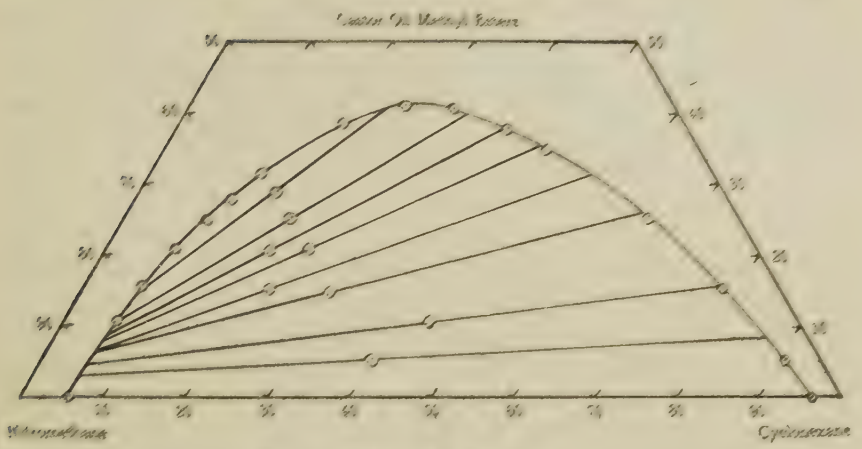

FIG. 1. Triangular Diagram.

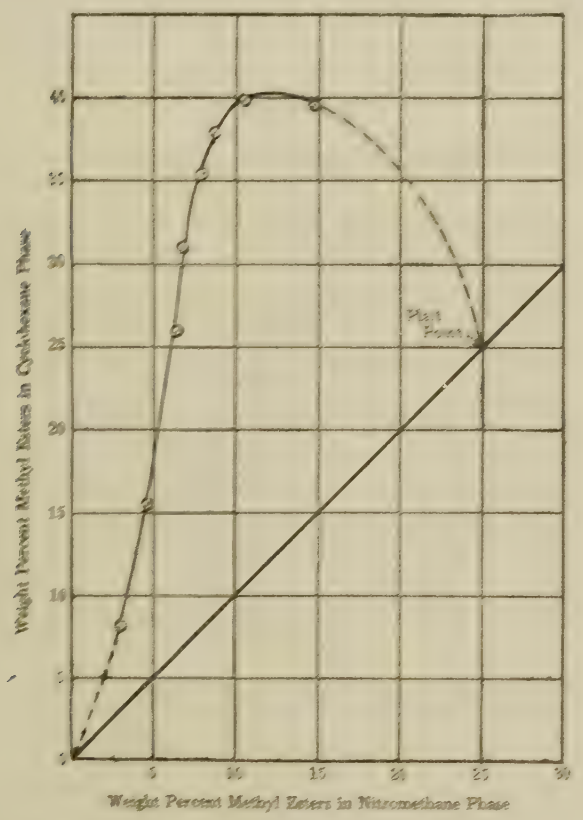

FIG. 2. Equilibrium Distribution Diagram.

esters in cyclohexane phase is plotted against the weight percentage of methyl esters in nitromethane phase. The distribution curve shows that methyl esters are preferentially distributed in cyclohexane phase, but the hydroxyl values of ester fractions obtained from nitro-methane phase are much higher than that of the original esters and also the esters obtained from the cyclohexane phase have lower hydroxyl values than that of the original esters. The hydroxyl value of pure methyl ricinoleate is 179·5. The hydroxyl values of ester fractions from nitromethane are higher than this value at lower concentrations of esters in the mixture. This shows nitromethane has high affinity to hydroxy esters. The higher hydroxyl value of ester fractions from nitromethane phase may be contributed to the presence of methyl dihydroxy stearate. The heterogeneous region in this case is much greater than that of methanol-heptane or furfural-cyclohexane system. The plait point composition of the components are, castor oil methyl esters 25·0%, nitromethane 64·8% and cyclohexane 10·2.%

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Viscosity and Density of Ethanol-Water-Ethylene Glycol Solutions at 30°C

BY

M. Ramanujam and G. S. Laddha

(Department of Chemical Engineering, A.C. College of Technology, University of Madras)

ABSTRACT

In connection with the study of extractive distillation of ethanol from aqueous solutions, certain physical properties of ternary solutions of ethanol-water and ethylene glycol were required for analysing the composition of the ternary equilibrium samples. Density and viscosity of the ternary solutions of ethanol, water and ethylene glycol were, therefore, determined at 30°C and are presented in this paper.

Introduction

Determination of physical properties of solutions provide a simple means of analysing the composition of ternary liquid solution. The properties of density and viscosity were used to analyse the mixtures of ethanol, water and ethylene glycol in connection with the determination of vapour-liquid equilibria of ethanol-water system in presence of ethylene glycol. Density data for ethanol-water solutions are available at 30°C in the literature (1941). Similarly density and viscosity data for ethylene glycol-water system are also available (1952). However, as no data were available for the ternary system, viscosity and density data were determined at 30°C in the present investigation.

Materials used

Ethanol: Dehydrated ethanol supplied by Madras Medical Stores was distilled over metallic calcium. It had a density of d^{30}_4 0·7808.

Ethylene Glycol: Pure Glycol supplied by E. Merck and Co., Darmstadt was distilled under vacuum of 72 mm. of

Hg and the fraction collected at 120°C was used. It had a density of $d^{30°}_{4}$ 1·1063.

Water: Distilled water from laboratory supply was redistilled and used.

Experimental Procedure

Synthetic solutions of ethanol, water and ethylene glycol were prepared by weighing each of the constituents. Density and viscosity measurements were made in a thermostat maintained at 30·0 ± 0·05°C by a Fisher Electronic relay with a thermoregulator actuated by ether as the sensitive fluid. The true densities of the solutions were calculated applying the necessary air corrections to the weighings of density bottles. Viscosities were determined by means of Ostwald Viscometer supplied by A. Galenkamp and Co., London, U.K. The viscometer was calibrated with distilled water. The standard values of density and viscosity of water at 30°C were taken as 0·99567 (1941) and 0·8007 (1945) respectively. The absolute viscosity of the liquid sample was calculated by the equation.

$$\frac{\eta}{td} = C$$

Where η = viscosity of the liquid centipoise

t = time seconds

d = density, gm/ml

C = Calibration constant determined as 0·004030 for the viscometer.

Results

The density and viscosity data are given in Table 1. Figure 1 shows the density data plotted against concentration of alcohol on ethylene glycol free basis with the concentration of glycol as parameter. Figure 2 shows the viscosity data plotted in the same manner. It may be observed that the density curves in Figure 1 are almost linear especially at higher glycol concentrations.

Figure 2 indicates the existence of a maximum viscosity value for alcohol-water system even in presence of glycol, although increasing the glycol concentration makes the curves flatter until at 90% glycol concentration it is almost a straight line.

TABLE I

Densities and viscosities of Ternary Solutions

Composition Wt. %			Density	Viscosity
Glycol	Alcohol	Water	d_4^{30}	$\eta 30$
9·97	0·0	90·03	1·0080	0·9979
10·00	12·05	77·95	0·9881	1·4824
10·00	26·99	63·01	0·9624	2·0093
10·00	40·74	49·26	0·9331	2·1966
10·00	54·25	35·75	0·9016	2·1231
10·00	67·82	22·18	0·8676	1·8639
10·00	81·86	8·14	0·8307	1·4812
10·00	86·76	3·24	0·8168	1·3266
20·00	0·0	80·00	1·0205	1·2478
19·99	11·89	68·12	1·0004	1·8316
19·99	24·21	55·80	0·9777	2·2755
19·98	35·22	44·80	0·9532	2·4612
19·98	48·24	31·78	0·9230	2·4141
20·02	59·87	20·11	0·8000	2·1964
20·09	71·45	8·46	0·8591	1·8394
20·01	77·11	2·88	0·8432	1·6344
30·01	0·0	69·99	1·0332	1·5963
30·00	12·50	57·50	1·0105	2·2353
30·01	21·57	48·42	0·9914	2·5830
29·98	31·41	38·61	0·9682	2·7439
30·01	42·10	27·99	0·9409	2·7195
29·98	52·42	17·60	0·9129	2·5516
30·00	62·59	7·41	0·8849	2·2252
30·02	68·99	0·99	0·8659	1·9472
39·97	0·0	60·03	1·0458	2·0549
40·01	8·91	51·10	1·0290	2·6183
40·00	17·80	42·20	1·0097	3·0559
40·01	27·16	32·85	0·9861	3·2197
40·01	36·16	23·85	0·9622	3·2270
40·02	44·90	15·08	0·9370	3·0345
40·04	53·61	6·35	0·9128	2·7547
39·96	59·19	0·85	0·8954	2·4526
50·05	0·0	49·95	1·0588	2·6885
50·00	7·53	42·47	1·0425	3·2164
50·00	15·07	34·93	1·0240	3·5681
50·00	22·50	27·50	1·0051	3·7762
50·03	29·92	20·05	0·9842	3·8144
49·94	37·55	12·51	0·9625	3·7470
50·00	44·71	5·29	0·9415	3·4288
50·00	49·35	0·65	0·9266	3·1727
59·99	0·0	40·01	1·0697	3·4815

Composition Wt. %			Density	Viscosity
Glycol	Alcohol	Water	d_4^{30}	η 30
60·02	6·00	33·98	1·0559	3·9348
60·02	12·25	27·73	1·0398	4·3111
60·00	17·23	22·77	1·0240	4·4653
60·02	23·92	16·06	1·0066	4·5756
60·05	30·30	9·65	0·9887	4·5255
59·99	36·39	3·62	0·9692	4·2353
60·01	39·43	0·56	0·9595	4·1483
70·00	0·0	30·00	1·0806	4·7565
70·01	4·31	25·68	1·0698	5·1544
70·00	8·60	22·40	1·0581	5·4686
70·00	12·46	17·54	1·0468	5·7138
70·01	16·46	13·53	1·0352	5·8197
69·98	21·51	8·51	1·0192	5·7636
70·00	26·81	3·19	1·0026	5·5924
69·98	29·63	0·39	0·9934	5·3860
80·02	0·0	19·98	1·0906	6·6127
80·00	1·85	18·15	1·0851	6·7280
80·00	4·23	15·77	1·0784	6·9448
80·01	5·72	14·26	1·0737	7·0938
80·00	8·44	11·56	1·0655	7·2706
80·04	11·12	8·84	1·0576	7·4198
79·95	14·26	5·79	1·0472	7·4518
80·02	17·86	2·12	1·0349	7·3215
79·98	19·76	0·26	1·0293	7·2182
89·99	0·0	10·01	1·0990	9·5936
90·00	1·52	8·48	1·0941	9·6263
90·00	3·00	7·00	1·0894	9·6561
90·00	4·68	5·32	1·0840	9·7087
90·05	5·93	4·02	1·0797	9·7692
90·00	7·48	2·52	1·0747	9·8128
90·00	8·92	1·08	1·0699	9·7884
89·98	9·89	0·13	1·0670	9·8544

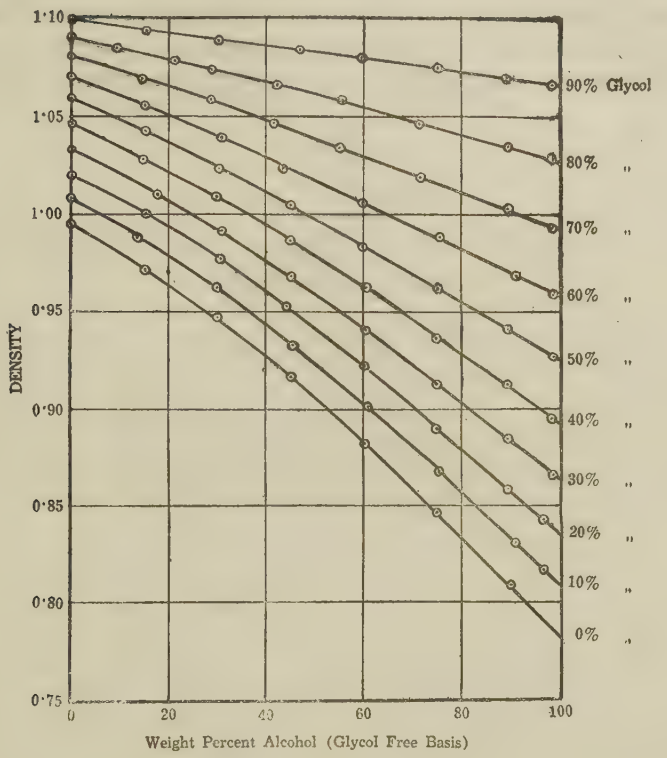

FIG. 1. Density — Composition Diagram

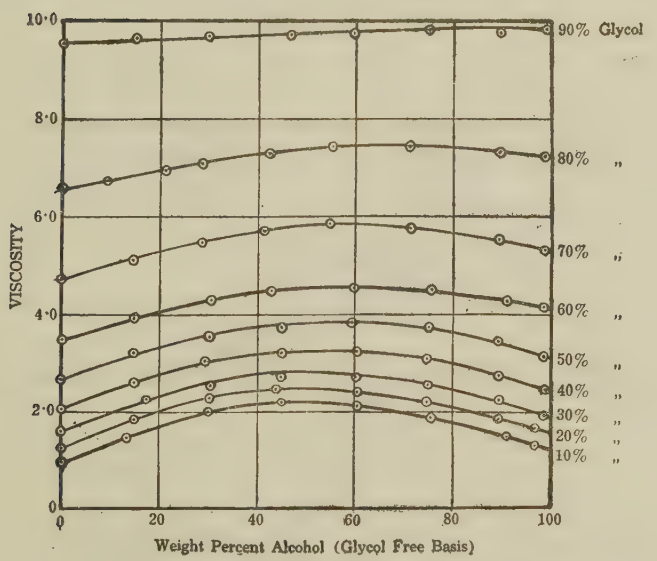

FIG. 2. Viscosity — Composition Diagram

Figure 3 has been prepared by cross plotting the experimental data at constant density and viscosity values on a triangular chart giving the ternary compositions. Such plots are useful for ana-

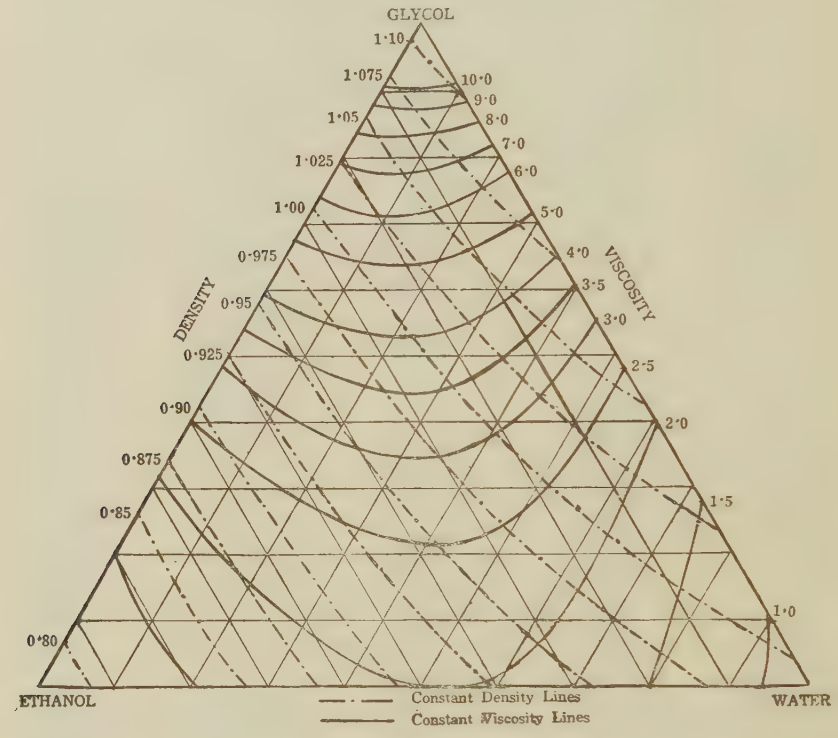

FIG. 3. Density and Viscosity of Ethanol. Water — Ethylene Glycol system.

lysing the compositions of the ternary solutions from the direct observation of viscosity and density of the solution.

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Studies in Filtration

BY

M. G. Subba Rau

(*Department of Chemical Engineering, A.C. College of Technology, University of Madras*)

A series of experiments were carried out on the filtration of the very compressible ferric hydroxide slurry with different ratios of filter aid. During the course of these experiments it was observed that the common belief that filter aids in any proportion tended to decrease the filtration resistance did not hold. The object of the present paper is to explain the phenomenon observed.

Equipment

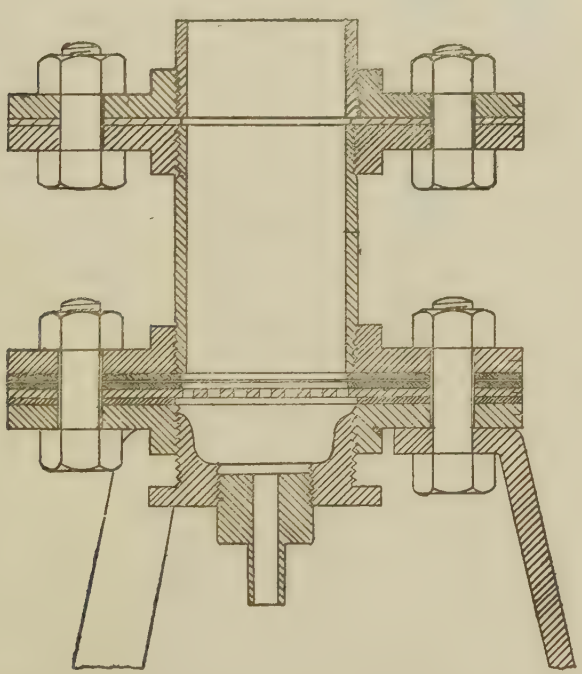


Fig. 1. Filter for fast filtering Slurries.

In carrying out experiments in the study of filtration, it has been the convention to use plant size equipment. Ruth (1933)

was the first to depart from this convention, followed by Carman (1935) Sperry (1916, 1944) and Hoffing and Lockhart (1951), who

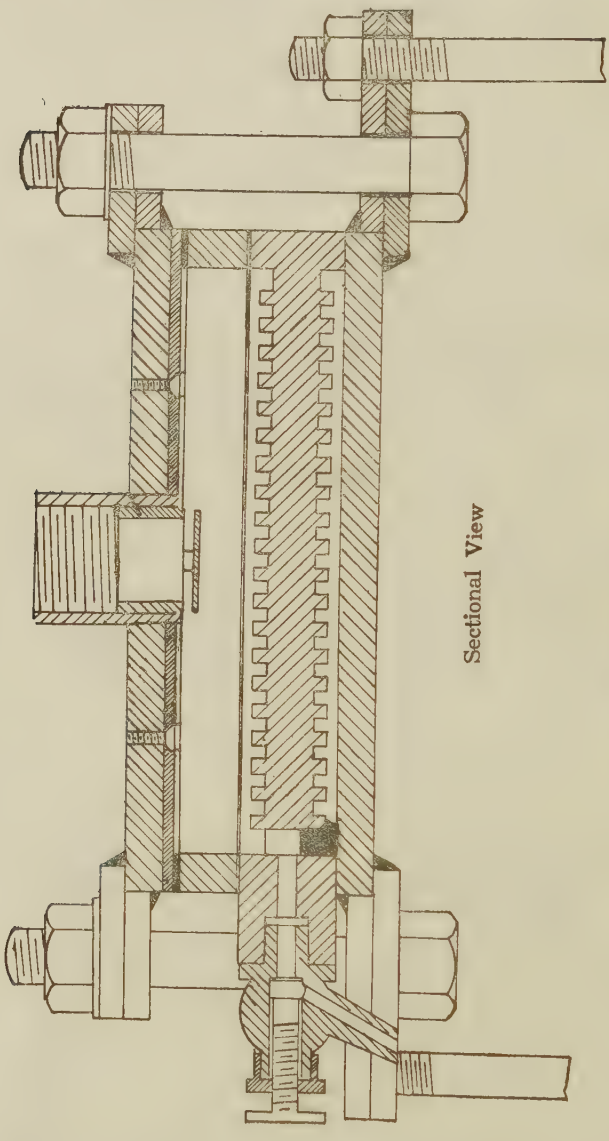


Fig. 2. Filter for slow filtering Slurries.

have all described small laboratory pressure filters used in their work. Of particular interest is that these filters require relatively small amounts of slurry and are capable of much greater precision than the usual semi-works size filter. The data obtained from

such small filters have been shown by previous workers, Burok & Storrow (1950) & Ruth & Kennye (1937) to faithfully predict the performance of large scale equipment.

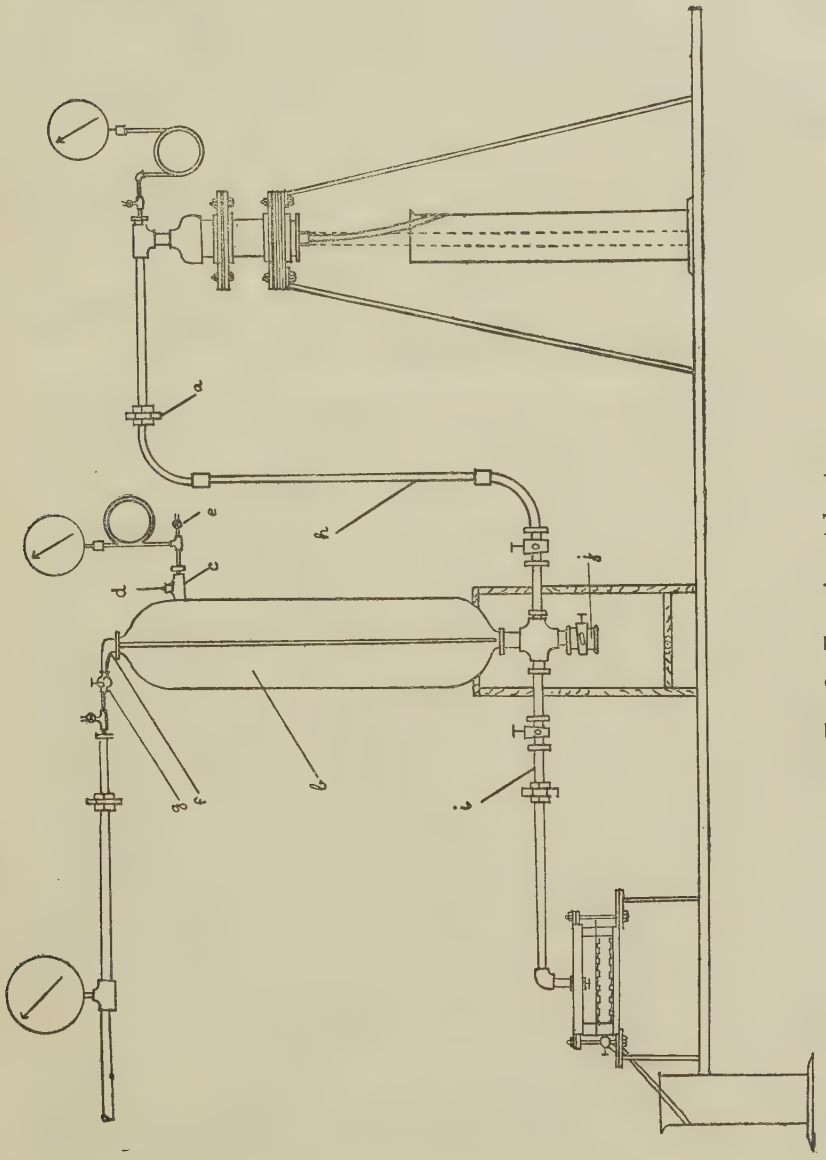


Fig. 3. Experimental set-up.

In the present work, two filters were constructed, (Figs. 1 & 2), one with an area of 2·04 sq. inches and the second with an area of 26·3 sq. inches, the smaller being used for fast filtering slur-

ries and the bigger for slow filtering slurries, to get over the problem of gravity settling of particles inside the filter. The former (Fig. 1) consists essentially of a pressure chamber made out of 1½″ galvanised iron pipe, 2″ long, with a polished interior to remove surface unevenness. Suitable flanges, filter cloth, gaskets and supporting base are fitted as shown in the figure. The latter (Fig. 2) is a single frame horizontal filter press, details of which have been shown.

All the experiments in filtration were carried out in pressures ranging from 10 to 50 lbs/sq. in. and this was achieved with the help of a montejus. A good agitation of the slurry was maintained by air being bubbled through the slurry.

The set up (Fig. 3) is so arranged that either of the filters could be used for any particular experiment.

The materials used in the investigation were ferric hydroxide and the filter aids. The slurries for the experiment were prepared under identical conditions as described below.

Ferric hydroxide was prepared from ferrous ammonium sulphate. Ferrous ammonium sulphate was dissolved in water. A little sulphuric acid was added to help dissolution. Commercial nitric acid was added to oxidise the ferrous salt to ferric. The solution was filtered to remove any suspended impurities. Sodium hydroxide 20 %, was slowly added keeping the solution stirred. At pH 6, precipitation was complete. Few drops of alkali were added to raise the pH to 7. The slurry was settled and the clear supernatant liquid siphoned out. The precipitate was washed three times with tap water to remove as far as possible any electrolyte. The precipitate was given four additional washings with distilled water. This elaborate process of washing was expected to remove all the electrolyte and colloidal hydroxide. To make sure that there were no aggregates, the slurry was passed through a Premier Colloid Mill. This slurry was then aged for fifteen days before use. Concentration of the hydroxide in the slurry was determined gravimetrically. Slurries of the required concentration were prepared by suitably diluting with distilled water. Even when preserved for one month, there was no observable change in the filtration characteristic and reproducible results were obtained.

The filter aids used were commercial samples of Filtercel and Hiflosupercel.

Since the degree of agitation is known to influence the performance of the cake, due to settling or erosion of particles, all agi-

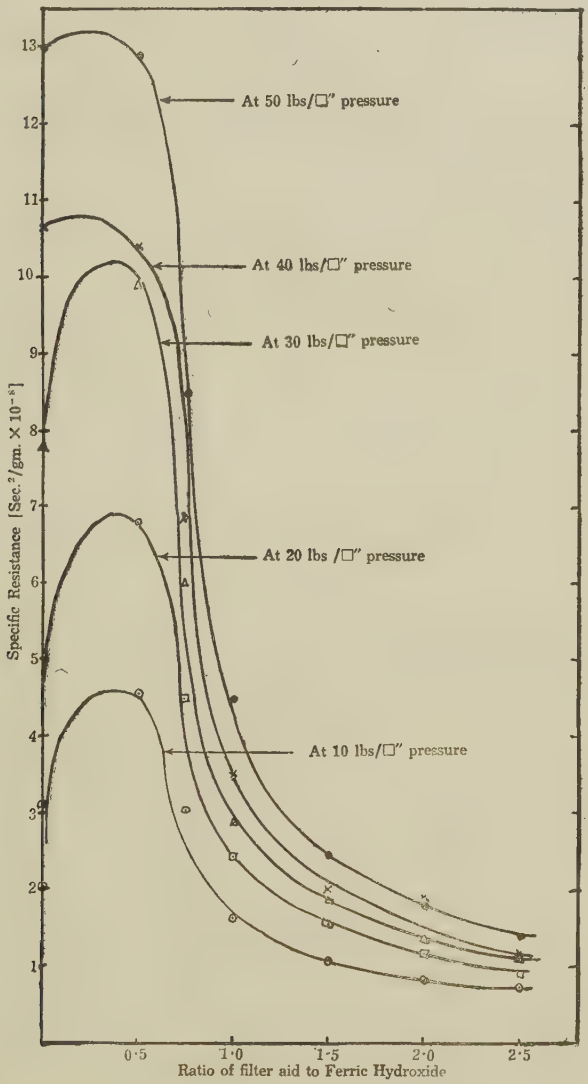


FIG. 4. Experiments with Filtercel.

tations were performed in identical manner so as to avoid any error due to variations in agitation. This ensured strict comparability for the values obtained.

Results and Discussion :

The results of the investigation are given in tables 1 & 2 and in Figures 4 and 5.

TABLE 1

Specific Resistance$^{\psi}$ of Various Mixtures of Ferric Hydroxide and Hiflosupercel at Different Pressures

Pressure lbs/sq. in	Ratio of hiflosupercel to ferric hydroxide						
	Nil	0·5	1·0	1·5	2·0	2·5	3·0
10	2·06	2·9	1·6	0·76	0·93	0·62	0·37
20	3·1	4·6	2·6	1·2	1·3	0·9	0·5
30	7·75	5·7	3·1	1·54	1·56	1·05	0·53
40	10·6	7·5	3·74	1·87	1·8	1·3	0·65
50	13·0	9·9	4·6	3·24	2·03	2·06	0·74

TABLE 2

Specific Resistance$^{\psi}$ of Various Mixtures of Ferric Hydroxide and Filtercel at Different Pressures

Pressure lbs/sq. in	Ratio of Filtercel to ferric hydroxide						
	Nil	0·5	0·75	1·0	1·5	2·0	2·5
10	2·06	4·55	3·05	1·63	1·08	0·77	0·74
20	3·1	6·8	4·5	2·35	1·56	1·2	0·88
30	7·75	9·8	6·0	2·85	1·93	1·34	1·14
40	10·6	10·4	6·7	3·48	2·0	1·9	1·07
50	13·0	12·9	8·4	4·52	2·42	1·7	1·38

$\psi = \text{Sec}^2/\text{ gm} \times 10^{-8}$

In the filtration of slimy materials it has long been realised that the rates of filtration can be improved by adding filter aids. Despite the wide use of filter aids little attention has been paid to the exact role of filter aids. Addition of solids to a suspension might be normally expected to decrease the rate of filtration

because of the increased volume of cake, whereas a filter aid has the reverse effect of increasing the rate of filtration. This has generally been explained as due to filter aid particles forming a rigid skeleton which takes mechanical stresses and leaves channels for the filter to pass through.

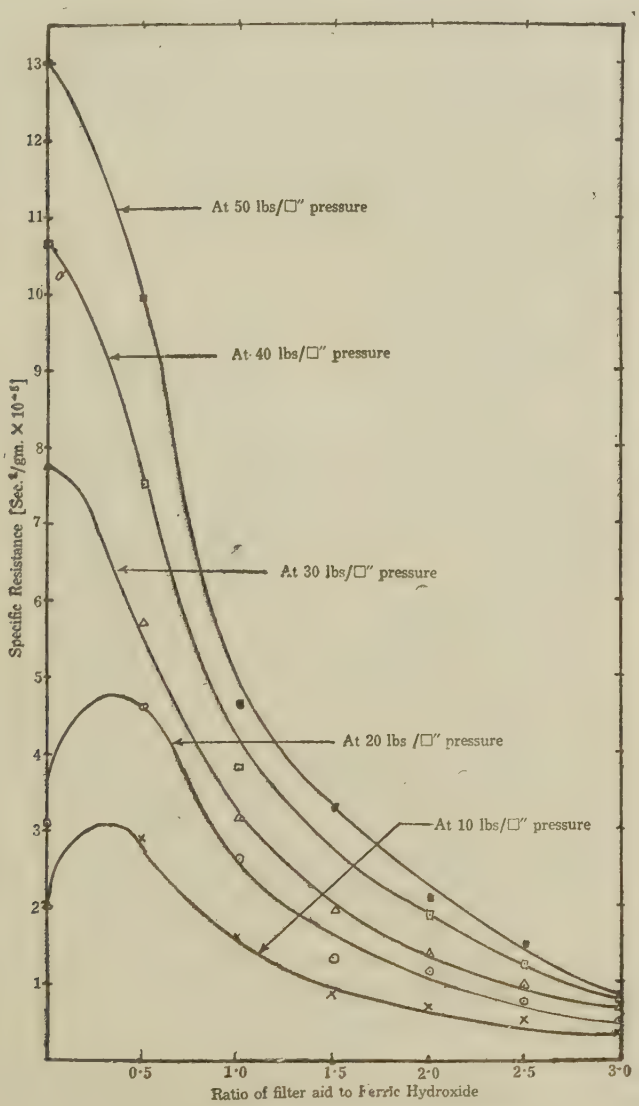


FIG. 5. Experiments with Hiflo Supercel

Carman (1938) in trying to explain the role of filter aids, worked with the hydroxides of iron and aluminium and with ferric

oxide using filtercel as the filter acid. Carman observed in the case of ferric oxide that when filter aid particles were few and scattered through the bulk of the cake, they merely served to increase the thickness of the cake and its resistance without giving the cake a more porous structure. In the case of the metallic hydroxides the resistance was found to be lower even with small amounts of filter aid. This anomaly, Carman explained, could not be attributed to stable structure formation alone. He was of the view that due to the opposite electrical charges present in the hydroxide (+) and the highly silicious filter aid (−), the hydroxide got firmly absorbed in the porous kieselguhr and thereby became a rigid integral part of the kieselguhr particle.

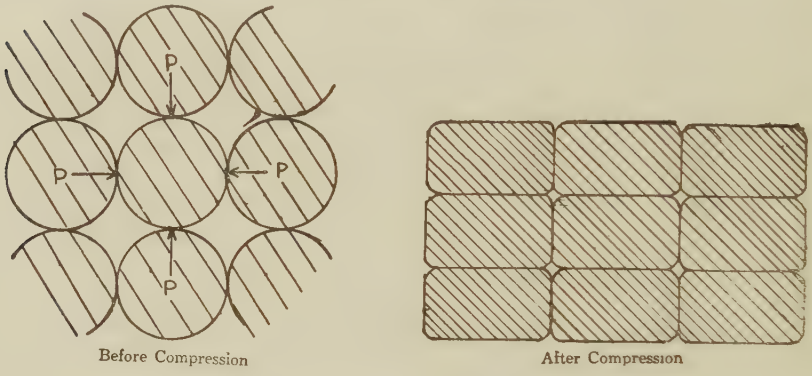
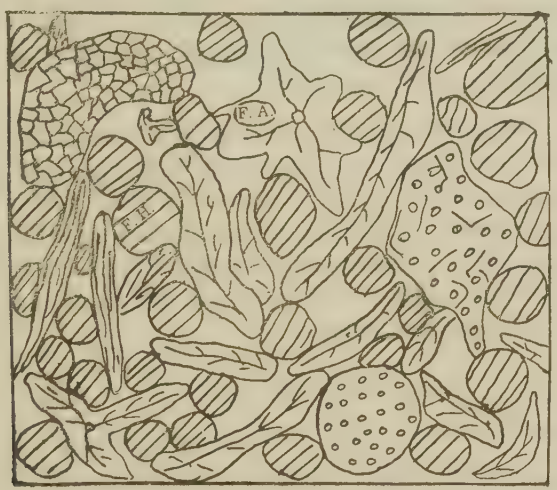


Fig. 6. Effect of pressure on compressible particles.

In the present investigations, work was carried out at five pressures 10, 20, 30, 40 and 50 lbs./sq. in., where as Carman worked only under 25 and 50 lbs/sq. in. It was observed at 10 and 20 lbs/sq. in., pressure with hiflo supercel and 10 and 40 lbs/sq. in., with filtercel, the specific resistance of the cake actually rose when small quantities of filter aid were added, but dropped appreciably when more filter aid was added. At higher pressures, however, the specific resistance fell from the very beginning. The changed relationship can be explained, in general terms, as due to the effect of higher compressibility of ferric hydroxide compared to that of the mixture of hydroxide and filter aid.

The rise in specific resistance at low concentrations of filter aid observed by Carman, only in the case of ferric oxide and not in the case of metallic hydroxide is observed in the present investigations for all cases, provided the filtration pressure is low. The observed phenomenon can best be explained as follows.

When a cake contains compressible particles, these particles get flattened by the incidence of an almost unidirectional pressure gradient. The incidence of pressure on any compressible particle is assumed to be more or less unidirectional as it is well known that the side thrust in a bed of solid particles is much less than the direct thrust. The capillaries in the cake get therefore lengthened and more tortuous, and the porosity of the cakes becomes considerably smaller. When a small quantity of filter aid is added, these rigid particles thinly distributed through the cake do not have any influence on the structure of the cake, and they only block the capillaries and increase the volume of the cake. At the higher concentrations of filter aid, the particles of kieselguhr are more closely spaced and in contact with each other forming a



F.A. Filter aid particle.
F.H. Ferric Hydroxide particle.
FIG. 7. Formation of a rigid skeleton.

rigid skeleton on the filter septum. The incident filtration pressure is borne by this comparatively rigid skeleton and the compressible filter cake particles are subjected to a lesser extent by a unidirectional pressure gradient. The result is that the compressible particles retain their original "near spherical" shape with a consequent increase in porosity. Maintenance of sphericity is further aided by the uniform "hydraulic" pressure exerted on all sides by the fluid. The relative incidence of pressure on the skeleton and on the compressible matter will be determined by the

ratio of filter aid to the compressible material. Thus at higher filter aid ratios, the porosity of the cake matrix will be higher leading to the observed continuous decrease of specific resistance with increasing filter aid content. At the higher pressure, on the other hand, it appears probable that on account of the greater mass and momentum of the individual filter aid particles, even the few particles present penetrate to the filter septum where they crowd together to build a skeleton sufficient to release the more or less unidirectional pressure on the first layers of compressible matter. Thus the highest specific resistance which occurs very near the cloth is reduced, thereby reducing the average specific resistance. A point in favour of the above theory is that the particles of hiflo supercel which are (by nature of their processing) heavier and bigger than those of the natural filtercel are able to exert their influence even at 30 p.s.i. because of their higher momentum whereas it takes about 50 p.s.i. for filtercel particles to produce the decrease in average specific resistance.

It is interesting to note that the average specific resistance of mixtures of filter aid and ferric hydroxide begins to fall below that of pure ferric hydroxide in all the cases studied where the ratio of filter aid to ferric hydroxide is more than 0·7 to 0·9. This is in consonance with the common industrial practice of using a minimum weight of filter aid corresponding to 100 % of the weight of compressible solids to be filtered.

Acknowledgment

I am grateful to late Dr. M. A. Govinda Rau, Director and Professor of Chemical Engineering, A. C. College of Technology, University of Madras, for the guidance and keen interest taken.

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Red Halophilic Bacteria

BY

A. Sreenivasan,

Fresh Water Biological Station, Bhavanisagar

"Wir möchten aber ..... diejenigen Bakterian als Halophile bazeichen, die auf Nahrboden ohne Salz auf solchen mit nur geringen Mengen uberhäupt nicht leban Konnen" (Golikowa 1930). The red halophilic bacteria are known to be associated with the reddening of salted hides and fish. As far back as 2700 B.C. in China, reddening of salted fish was noticed (Hardy, 1951). Though a study of these bacteria was initiated during the eighties of the last century (Edington, 1887; Mauriac, 1886-89; Farlow, 1880-1886; Layet, 1887-1889; Le Dantec, 1891-1906), considerable tempo was given by workers in the field of leather bacteriology in the twenties of this century (Bergmann, 1920; Stather, 1928; Llyod, 1929; Robertson, 1931; 1932; Hansam, 1931). Most of these earlier studies did not go beyond mentioning that chromogenic bacteria were isolated from salts, salted hides and fish. The progress in this field has been limited and investigations were not continuous. For example after Gibbon's work (1936), the next publication on this subject was only by Hess (1943) and a further decade had to elapse for the work to be resumed (Katznelson and Lochhead, 1952: Castell 1950 a, b, c, 1952: Dussault, 1952). During the present decade great interest in these specialized group of bacteria has been evinced by workers in Canada (Dussault, 1954; Dussault and Lechance, 1952: Gibbons and his colleagues, 1952, 1955, 1954; Katznelson and Lochhead, 1952) and in India (Venkataraman and Sreenivasan 1954, 1956, a, b, c; 1957). More intensive studies are needed on the biology, ecology and physiology of these bacteria if great losses to leather and salt fish trade is to be minimised.

A recent review by Hannery (1956) has dealt with "Halophilic" bacteria, including non chromogenic varieties as also facultatively, halophilic bacteria. It is therefore proposed not to deal with them here, not even with halophilic fungi affecting salted goods nor with reddening due to other causes. Only the "Red

Halophilic bacteria" which fail to grow below a salt concentration of 10% Nacl are discussed, (Bitting, 1911; Cobb, 1916, 1927).

Ecology of the Red Halophilic Bacteria

Mauriac (1886-89), Le Dantec (1891, 1906), Hoye (1906-1908), Farlow (1880), Bitting (1911) and Cobb (1916, 1927) found that salts used in curing were the originators of reddening. Lloyd (1929) found that "red" was introduced on hides by marine salts. Bothello and Frexio (1949) traced the reddening of salted cod to the marine salt used in Portugal. Wlassova's (1932) extensive researches had shown that red halophilic bacteria were found in crude solar salts but not in kiln dried salts or artifically evaporated vaccum pan salts. Nor were they found in any one of the 62 mined salts. Soudan (1955) also recorded the absence of red halophiles in mined salts as against their abundance in marine salt. Gibbons (1932) too traced the origin of red halophiles to salterns in which solar salt is prepared and indicated that mined salts are free from them. Surprisingly enough these organisms were later found in 7 mined or evaporated salts (Gibbons, 1936). Clayton and Gibbs (1927), Harrison (1923) and Shewan (1937) also traced them to solar salts while Kurochkin and Emil Yanchik (1937) found them in Lake salts of S. E. Russia. Dixit and Vaccha (1942) found similar organisms in Sambhar lakes of Rajputana though Venkataraman and Sreenivasan (1955, 1956) did not find them in any great numbers even in 'Pink' salts. This 'pink' colour of salt was attributed to algae (Sapre and Mehta, 1955). Though all these workers found them in solar (Marine and lacustrine) salts the actual origin was not traced. Solar salt is itself a product of evaporation of salt-water from seas or salt lakes. Poulsen (1878) first isolated *Sarcina littoralis* from marine mud off Copenhagen. From seawater itself however, it has not been obtained though Hess (1942) used enrichment techniques. He did not also find them in the intestines of fish but found them on the slime of two cod fish. From these evidences it should be considered that marine muds used for evaporating salts and also the salterns are the sources and habitat of these groups of bacteria. The special ecological conditions obtainable appear to be the higher concentration of salts due to evaporation and the special effect of solid particles were perhaps the salt is concentrated. The work of Stuart (1938) is however discordant with these results. He claims to have isolated halophilic bacteria from soil, water, dung etc. But evidently these are "halotolerant" (Golikowa, 1930) and not truely halophilic.

Similar organisms have been also recorded by Venkataraman and Sreenivasan (1954) and Robertson (1931).

Biology and Classification of Red Halophilic Bacteria

The red, obligately halophilic bacteria are mainly rod forms and cocci. But they are highly pleomorphic, the shape depending on the environment (Lochhead, 1934). This complexity is seen in their being mistaken for myxobacteria (Stuart et al, 1934, 1936) and Amoebobacteria (Penso, 1947). Pijper (1952) affirms that they are twisted ribbon—shaped or sprial after studying them with his famous, "sunlight dark-ground microscopy". The presence of gas vacuoles was found by Klebahn (cited by Petter (1932)) and later confirmed by Petter (1932). But Pijper (1952) who also observed these light scattering inclusions did not consider them to be gas vacuoles but as products of degeneration. Houwink (1956) quite recently showed the presence of these vacuoles by electron-microscope. He further detected the presence of a tuft of polar flagella. The cell wall structure was found to be more related to *Spirillum* than to *Pseudomonas.* Molisch considered the gas vacuoles to be sulphur bodies but Stuart (1935) agreed with Petter (1932) in considering them as gas vacuoles. Stuart (1935) records that these red salt bacteria develop as cystlike colonies resembling some algae. They burst and liberate cocci and *Sarcina.* It is however clear that Stuart was dealing with a contaminated culture in low salt media since these "cysts" could not be produced in "high salt media". In fact Cloake (1923) found a bacterium, an alga and fungus on salted fish. Velu (1929) thought that the red bacteria found on salted fish were mutants of *Bacillus prodigiosus,* which is patently incorrect. We have been able to isolate in our laboratory a large number of red *Bacillus sp.* (Sporeformers) from salts as well as salted fish but these were never found to produce the 'pink' in them and further these were not obligately halophilic, since they grew also on nutrient media without salt. Petrowa (1935) observed pleomorphic "Velu rods" in salted fish and described a coccus form, viz. *Tetra coccus carneus halophilus.* It is thus possible that the confusion in the classification was a result of impure cultures. At high salt concentrations all sorts of 'bizarre' shapes are assumed by bacteria. Lochhead (1934) has in fact noted a stage in the life cycle of *Pseudomonas salinaria* analogous to the "swarmers" of *Rhizobia.* He also noted the disintegration of the cells from the granular symplasm from which, the granules or "regenerative units" may form vegetative cells.

"Large coccoid form (Gonidangia) with budding" (Lochhead, 1934) resemble the "ovogigantoid" cells (Bertullo, 1956). *Pseudomonas salinaria* according to this author produced "minimum reproductive units" which were filterable-L forms. These observations of Bertullo are very original and the progress in this line will be watched with interest, since it throws light on the biology of Red Halophilic bacteria.

The classification of red halophilic bacteria presents a difficult problem. It is however doubtless that these belong to Eubacteriales, despite Stuart's misclassification of them into *Myxobacteriales,* which might be due to incorrect appraisal of the pleomorphism of these bacteria. The arrangement of cocci gives rise to two genera, viz., *Micrococcus* and *Sarcina*. This distinction sometimes is without any difference. This has given rise to a maze of confusion in the nomenclature and identity of some of the organisms—*Diplococcus gadidarum, Micrococcus gadidarum, Micrococcus littoralis, Sarcina littoralis, Sarcina morrhuae, Micrococcus morrhauae, M. roseus halophilus, Tetracoccus carneus halophilus,* etc. The morphological distinction between *Micrococcus* and *Sarcina* is based on the tetrad or packet formation by *Sarcina* and absence of this in *Micrococcus.* But packet formation depends to some extent on the mode of cultivation, medium, etc. Only organisms known to produce packets consistently in a medium can be called a *Sarcina*. The description of *S. littoralis* (Lochhead, 1934) gives an impression that it is a Micrococcus. Gibbons (1936) and Venkataraman and Sreenivasan (1956 a, b) considered that S. *littoralis* is in fact a Micrococcus. On the other hand *Sarcina Morrhuae* was shown to be a true sarcina and *M. morrhuae* a true *Micrococcus* (Venkatraman and Sreenivasan, 1956). The culture designated as *Micrococcus roseus halophilus* is also a micrococcus since packet or tetrad formation is neither regular nor constant. For similar reasons, confirmation of the identity of *Dilpococcus gadidarum Backwith* (*Penso,* 1955, 1947) appears avoidable. There has been some mention that *Sarcina littoralis Poulsen Sarcina Morrhuae Farlow* and *Micrococcus morrhuae* are identical (Stuart *et. al.* 1953). An examination of these cultures has shown that each is a distinct species differing from the other in morphological and biochemical characteristics (Venkatraman and Sreenivasan, 1956 a).

The rod forms do not present much difficulty in identification. *Pseudomonas salinaria* Harrison and Kennedy, *Ps. cutirubra*

Lochhead, *Bacterium halobium Kellerman* and *Bacterium—trapanicum* Petter are recognized as distinct species. Bernouli *et. al.* (1948) in Switzerland isolated an obligately halophilic Gram negative bacterium from Swiss salt and named it *Bacterium rauricum*. Later, Anderson (1954) and Venkataraman and Sreenivasan (1956b) have added a number of new species. The rod forms generally appear to be highly pleomorphic. Our cultures, *Halobacterium indicum* showed all odd shapes such as stout, oval, fusiform, concrete, cleavate as well as simple bacillary forms. At some stages they appeared to be vacuolated. An interesting report has appeared about the gliding movements as in *Amoebobacter morrhuae* Penso (1955). This nomenclature seems to be misapplied and is without firm basis. Likewise the description of halophilic bacteria as belonging to the higher bacteria, *Myxobacteriales* (Stuart, 1934, 1935, 1936), is also misleading and may be due to incorrect appraisal of the pleomorphism of these bacteria. Further Stuart and his associates used media with low salt concentrations, which casts doubt on the halophilic (obligately) nature of these bacteria. It is now clear that red halophilic organisms mainly belong to *Eubacteriales*. Though variously classified from time to time under Serratia, Pseudomonas, and Bacillus, the need for a rational classification was felt for a long time. Harrison and Kennedy described *Pseudomonas salinaria,* which was later described as *Serratia salinaria* by Lochhead (1934). Still later Lochhead (1934) felt justified in including this and *S. cutirubra* in the genus *Pseudomonas* because of the polar flagella and the habitat and physiology. Schoop (1934) suggested the genus *Halobacterium* for the red halophilic bacteria. Elizarivolcani (1940) described the characteristics in fuller detail and named the genus *Halobactrium* Elizari-volcani. Anderson (1954) who worked with a number of cultures suggested the name *Halobacter* but on grounds of priority *Halobacterium Elizeri Volcani* (1940) has been accepted for the Bergey's manual 7th Edition (in press). *Polar* flagellated, obligately halophilic, red chromogenic rod forms are included in the genus *Halobacterium*. It should however be cautioned that flagella staining of red halophilic bacteria is very difficult and that non-motile forms also occur. Hence the genus *Halobacterium* should include, all Gramnegative, non-sporeforming, red salt organisms which grow in salt concentrations of 10 to 30 %, motile with polar flagella or non-motile. These possess carotenoid pigments which is quite characteristic of this genus.

Biochemical characteristics: The reddening organisms occur on the surface of the exposed portion of fish in brine but *not in the submerged side.* In laboratory cultivation, growth occurs only on the surface. Growth is also very poor in liquid media. All these indicate the facultative aerobic metabolism. Stuart (1940) considered this to be merely surface tension effect. Venkataraman and Sreenivasan (1956c) have cultivated these on filter paper strips dipping partially in a liquid medium. Surface tension depressants like sodium ricinoleate actually prevent the growth of cocci (Venkataraman and Sreenivasan 1956d).

Generally the red halophiles are not saccharolytic (Lochhead, 1934; Gibbons, 1936; Pette, 1932; Bertullo 1954; Penso, 1947; Venkataraman and Sreenivasan 1956a, b, c). Hydrolysis of starch is fairly common and in some cases as *Micrococcus morrhuae* deep depressions or "pits" are formed in starch media (Venkataraman and Sreenivasan 1956a) due to digestion of starch. Gibbons (1957) stated that starch hydrolysis is a diagnostic reaction in the classification of halophiles. He found that only 9 out of 49 strains hydrolysed starch. He has pointed out the difference between the findings of Elizarivolcani (1940) and that of Venkataraman and Sreenivasan (1956a). It would be pertinent here to restate that *M. morrhauae* is very strongly amylolytic, not only hydrolysing starch (0·2 % concentration) in conventional media but also in starch-based solid media (Sreenivasan and Venkataraman 1956). Similarly the difference noted by Lochhead (1934) and by Venkataraman and Sreenivasan (1956b) in the ability of *Sarcina littoralis* to digest starch is explained. The latter authors used 20 % NaCl media. Gibbons (1957) thinks that the ability to hydrolyse starch may be lost on long laboratory cultivation. Only three of the ten strains studied earlier by Venkataraman and Sreenivasan (1954) hydroloysed starch.

Nitrate reduction is variable and not very marked (Venkataraman and Sreenivasan, 1954, 1956, a, b, c), Gibbons (1957) and Bertullo (1956) found none of the red rods reduced nitrates. The medium used is important as shown by Sreenivasan and Venkataraman (1956 a, c). Indole is produced by most of the red halophiles, especially the rod forms (Venkataraman and Sreenivasan 1956 a, b, c; Gibbons 1936, 1956). Negative result was reported by Bertullo (1956). Gibbons (1957) was not in agreement with the negative results for indole production reported by Venkataraman and Sreenivasan (1956 a, b). The latter authors using a

very sensitive casitone-medium (Sreenivasan (1956c) detected indole in rod forms but not in cocci except *M. roseus halophilus*. As regards H_2S production negative results were reported by Venkataraman and Sreenivasan (1954, 1956, a, b; Bertullo, 1956) but Gibbons (1936, 1957) and Lochhead (1934) have described some positive cultures. Casein digestion and gelatin hydrolysis were not marked but by the use of proper media (Venkataraman and Sreenivasan 1956 a, b; Sreenivasan and Venkataraman 1956) many red salt bacteria were found to digest casein slowly. Gelatin liquefaction is not always positive in Gibbons medium but gelatin hydrolysis can be detected better in Sreenivasan and Venkataraman's medium. Proteolysis is clearly noticeable in this medium. Production of off odours in certain media is also chaaracteristic of some of these red halophiles.

Physiology of the obligate halophiles: By definition, these group of bacteria thrive at an optimum concentration of 18-25 % NaCl with minimum of 10 %. That the effect is not purely osmotic is proved by the work of Schoop (1935) and Robinson and Gibbons (1952) who were unable to grow them in isotonic NH_4 Cl, Na_2SO_4, KCl etc. Neither Cl nor Na ions alone could support growth. Hence the requirement of NaCl is specific. One culture described by Venkataraman and Sreenivasan (1954) however grew when KCl replaced NaCl.

Till very lately the enzyme system of red halophilic bacteria have not been studied and hence their metabolic activities are not clear. Robinson and Katznelson (1953) established the presence of an aspartate-gulutamate transaminase system in *Pseudomonas salinaria* and this was active at an optimal pH of 8·0 when the NaCl content was 4 to 8 %. The resting cells did not oxidize readily the common carbon compounds usually employed. Baxter and Gibbons (1954) showed the presence of glycerol dehydrogenase in *Ps. salainaria* which had a pH optimum of 10·0 and which oxidized glycerol to dihdroxyacetone. However d-sorbitol, d-mannitol, ethanol, and 2, 3. butanediol were not oxidized. This enzyme resisted a temperature of 60°C for 90 minutes with 20 % salt. The effect of salts on the enzyme appeared to be ionic rather than osmotic. The glycerol dehydrogenase from *Ps. salinaria* was more resistant to salts than analogous enzymes from non-halophilic bacteria, confirming the work of Robinson and Katznelson (1953) with regard to another enzyme. Though the basis for requirement for salt is not known it is assumed that there is a change in the enzyme

molecule which makes it most active in the presence of high concentration of salt and also renders it inactive in the absence of salts, thus linking this with obligate halophilism. Presence of Cysteine desulphydrase in *Ps. Salinaria* was established by Baxter and Gibbons (1957). The enzyme was present in cells grown in 15-30 % NaCl media. H_2S was liberated from cysteine by this enzyme, which is activated by potassium chloride. Katznelson and Robinson (1956) reported that *Ps. salinaria, Ps. cutirubra, Sarcina littoralis* and *Sarcina sp.* Strain 63 N2 all oxidize pyruvate to acetate suggesting the presence of an active system for terminal oxidation. *S. littoralis* alone oxidized succinate to fumarate. In glutamate oxidation, oxidized succinate to fumarate. In glutamate oxidation, a-Keto glutarate did not accumulate in indicating further oxidation. Both the Pseudomonads oxidized l-aspartic and l-glutamic acids completely whereas *Sarcina* did so partially. Under normal conditions ornithine was rapidly oxidized by three of these species and in special media even decarboxylated. Glycerol and dihydroxy acetone were also utilized but gluconate and xylose were oxidized very slowly. A similarity of the two Pseudomonads in their oxidative ability was noted. The non-chromogenic *Sarcina* differed from others in the ability to oxidize rapidly glucose, fructose and mannose. Growth factors such as thiamine, Pantothenic acid, nicotinic acid, folic acid, p-amino benzoic acid, biotin, uracil, and choline did not stimulate the growth of red halophiles, *S. littoralis*, *Ps. cutirubra* and *Ps. salinaria*. Yeast extract appreciably improved growth of these organisms. The complete growth factor mixture plus cystine and thymine did not replace yeast extract whose effect was not replaceable by its ash (Katznelson and Lochhead, 1952).

A high demand for Mg^{++} by these red halophilic bacteria was noted (Dussault and Lechance, 1952) and by Katznelson and Lochhead (1952). This was confirmed by Venkataraman and Sreenivasan (1955) who found that common salts containing no or low Mg content harboured none of very few red halophiles while common salts containing high Mg had appreciable number of these. They also recorded better growth in media with 1% $MgSO_4$. Brown and Gibbons (1955) also noted the high Mg requirement of red halophiles but no explanation was offered for this. It was greatly in excess of the quantities required by known Mg activated enzymes. This ion did not seem to be incorporated into the cell. Morphological changes of rod forms (but not cocci) in Mg deficient media was noted by them. They found potassium to be essential and that it seemed to be stored in the cell and could

partially replace Na. The iron requirement of halophilic bacteria was similar to that of other bacteria. The chemical composition of the cells of red halophilic bacteria was studied for the first time by Smithies et al. (1955). It was shown that they had a high nitrogen and low carbohydrate content. The only sugar present was ribose, in the form of ribose nucleic acid, an unusual feature. They had a lower phosphorus and higher fat content than *M. pyogenes* and *B. subtilis*. But halophilism is still not explained by these. Smithies and Gibbons (1955) found DNA slime layer in halophiles but the functional relation of these slimes to halophilism was not known. The slime could not be involved in any essential physical or chemical reactions at the cell surface. First report of the immunological ractions of red halophiles was given by Baxter and Gibbons (1955). *Ps. Salinaria* was found to produce no antibody.

Cultivation of red halophilic bacteria: Flannery (1956) has reviewed the literature on this aspect. Dussault and Lechance (1952) described an improved medium for culture and study of red halophiles on solid media based on their high demand for Magnesium. This was definitely better than the classical Lochhead's medium. Clayton (1927) has used starch media but they were not suitable for plate culture due to clumping. Sreenivasan and Venkataraman (1956) have described two media based on rice starch viz., Prawn broth-starch and Rice-milk-salt media. Both of them were excellent for growth and cultivation. They have also described liquid media in which red halophiles were grown on a strip of filter paper dipping into these. Rowan (1956) proved the utility of Rice starch media.

Control of the red halophilic bacteria: The control of red salt bacteria is still a problem since salt itself is the carrier of infection. Though curing plants and equipments could be sterilized by chemical means, salt or salted fish cannot be so easily disinfected. Addition of chemicals that might control the red halophilic bacteria, to fish may involve toxic hazards. Hence control must start at the manufacturing stage of salt. Rock salt has been reported to be free from red halophilic bacteria (Shewan 1951; Stuart, 1933 Gibbons, 1932; Venkataraman and Sreenivasan 1956c). Salts prepared by mechanical evaporation and drying may be almost sterile for eg., the vacuum pan salt. Kiln dried salt was free from red halophiles (Stuart *et. al.* 1933). Candian workers (Dussault, 1954a) invariably found millions of red halophiles in salts but in

India (Venkataraman and Sreenivasan 1955) and South Africa (Rowan 1956) such large numbers have not been encountered though the same "drop-plate" procedure (Dussault 1954) was followed by them. Reduction of the Mg. content of salts may greatly reduce the load of red halophiles carried by salts. Soudan (1955) has tabulated the literature on the use of various chemical and fumes in the control of red salt bacteria. Petrova (1935) suggested the use of boric and benzoic media and borax for control sterilization of salts and disinfection of utensils. Canadian workers (Annual report, Fisheries Research Board, 1954) reported the inefficiency of aureomycin in controlling the red halophiles. Venkataraman and Sreenivasan (1956d) confirmed it and offered a possible explanation for this. They also found that nitrite at 0·2 % suppressed the rod forms but not the cocci which survived even 0·5 % nitrite while sodium ricinoleate suppressed the cocci but not the rods at 0·2 % concentration. Dussault (1956) obtained the opposite results by the use of ox-gall. This suppressed *Ps. salinaria* but not *Sarcina littoralis* and hence the use of ox-gall was suggested for differential isolation of red halophiles. Since Mg. in the salt is supposed to have a stimulatory action on red salt bacteria, it would be worth while trying the use of complexing agencies to remove Mg. It is surprising that red halophiles did not develop in "Semi dried prawns" (Venkataraman and Sreenivasan) 1953) with 12 % NaCl nor on fully salted and dried prawns with 20 % and 25 % NaCl. Of further interest is the fact that the aqueous extract of prawns stimulates rapid and profuse growth of red salt bacteria. The free amino acids detected in this prawn were arginine, glycine, serine, proline (strong), aspartic acid, glutamic acid, threonine, alanine, leucines, methionine and lysine. Bitting (1911) also noted that red bacteria grow best on salted cod and haddock, less so on salted cusk, and least in hake. The difference could not be accounted for by their gelatin content nor by the acidity of flesh.

Sterilization of salt by heating has been suggested by many workers (Harrison, 1923; Hardy 1951; Gibbons, 1932; Soudan 1955; Velu, 1929; Castell, 1950; Horowittz-wlassova, 1932, Cobb, 1927). Hess (1940) recommended various chemicals and sprays for control of these bacteria in curing-plant, sheds etc. Castell and Mapplebeck (1952) found that copper sulphate, quaternary ammonium compounds, formaldehyde etc., had very little effect on red halophiles. However 2% lye and strong chlorine (200 p.p.m.) were effective. The pH range for the growth of red halophilic

bacteria was reported to be 5·5-to 9·0 (Hess, 1942; Soudan, 1955) The optimum pH was found to be 7·4 to 7·6. We have noted that mackerel which were in brine at pH 5·4 for 5 months still retained viable red halophiles which developed on them when they were removed from the brine dried and stored for 15 days. A new rod form in pure culture was obtained from it (Sreenivasan and Venkataraman, 1958). The brine itself on further storage for 2 months in sterile bottle developed a surface scum of red halophiles. Relative humidity seems to be an important factor (Hess, 1942; Mossel, 1956). Long storage of salts destroyed red halophilic bacteria (Hof. 1935; Castell 1950 a, b,b, c.). Dussault (1954b) recommended the use of antagonistic bacteria to control red halophiles. Further knowledge of the physiology of these bacteria may help us to control them.

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Observations on the Food and Feeding Habits of Post Larvae, Juveniles and Adults of Some Madras Fishes

BY

M. D. K. KUTHALINGAM

Zoology Research Laboratory, Chepauk, Madras

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ABSTRACT

In the present investigation the life histories and feeding habits of three fishes *Stolephorus indicus, Hemiramphus georgii* and *Scomberomorus lineolatus* whose eggs could not be obtained from the inshore waters of Madras are described from post-larvae collected from the sea. A brief resume of the previous work regarding the food and feeding habits of larval and adult fishes done both in India and abroad is given. The composition of the earliest diet of the post larvae the later changes in diet during the subsequent stages are described fully on the basis of experiments conducted on their feeding. The data gathered regarding their larval diet are compared with those of the adult diet.

Introduction

Though the value of rearing the larvae from the eggs and studying and preparing the food chart of each fish from the commencement of the feeding has been realised and nearly 10 species have been so studied, yet so far as the following 3 species are concerned, the eggs were not available in the inshore area of Madras and they had to be studied from the post larval period. It is possible that these 3 species breed in the offshore area since their post larvae enter the inshore area at a fairly early condition. As the facilities for the offshore collections are limited at Madras it was felt however that the data concerning the later development and the changes in the feeding habits may be reported without delay.

1. *The Food and Feeding Habits of Post-Larve, Juveniles and Adults of the Stolephorus Indicus (V. Hass)*

The food and feeding habits of the clupeids have been studied by many outside India. But the species of the genus *Stolephorus*

being confined to the India and Java seas, have not come in for much attention. Except for the studies of Bapat and Bal (1950) on the food and feeding habits of *Stolephorus tri* and *S. commersonii,* the brief note by Gopinath (1942) on the food of young *Stolephorus tri* and the life history of *S. tri* by Vijayaraghavan (1953) there is no published account on the food and feeding habits of the larval and juvenile forms of *Stolephorus.* Hence the feeding habits of *Stolephorus indicus* of Madras during the post-larval, juvenile and adult stages are presented here.

A total number of 108 advanced post-larvae measuring 16·4—22·4 mm. were collected from the five in-shore plankton hauls made on 20th, 22nd and 28th of March, 1957. Except in size there was no difference in these larvae. The median fins were not continuous and had developed rays while the pectoral fins were semi-circular with developing rays. The larvae were free from pigmentation but for a few black pigment spots present along the alimentary canal. The anterior portion of the alimentary canal was straight and narrow whereas the posterior region was considerably enlarged. Twenty-six pre-anal myotomes were counted after fixing, staining with boraxcarmine and clearing in cedar wood oil. The muscles of the myotomes also had the typically clupeid arrangement described by Delsman (1922). The caudal fin was deeply forked, the ventral fin was developed as a flap in the region of the eighteenth myotome and the anal fin had fin-rays. The eyes were silvery as in the adult and the iris was pigmented. The head was elongated and the jaws were very well developed. (Text-fig. 1)

Out of 108 larvae collected from the plankton, eighty-six of varying sizes were fixed as soon as they were brought to the laboratory in order to study their food and feeding habits. The remaining larvae were reared in the laboratory in dishes kept in a cooled chamber.

The stomach contents of sixty-six post-larvae 16·4 — 18·8 mm. long revealed that they fed only on adult copepods such as *Oithona rigida, Temora sp, Paracalanus parvus, Macrosetella gracilis, Euterpina sp* and *Pontellopsis herdmanil.* Twenty larvae 19·2 mm. — 22·4 mm. long showed that 66·2% of the food were of copepods, *Temora sp, Acartia sp, Oithona sp, Macrisetella gracilis, Euterpina sp, Pontellopsis sp,* and *Corycaeus sp.* 22·4% of the food was composed of *Acetes sp,* and the remaining 12·4% consisted of *Lucifer* and *Squilla* larvae.

Larva 25th day after collection :

Though the post-larvae had grown to a length of 33·2 mm. there was not much difference in the external features or their feeding habits. But during the next nine days though the growth became slack all the features of the juvenile stage were acquired.

During this period of nine days a change in diet also was noticed. When these post-larvae were supplied with fresh unsorted plankton and observed under the binocular it was found that they had started feeding on larval and young forms of clupeid, Engraulid and Leiognathid in addition to copepods.

Larvae 34th day after collection (Text— Fig. 2) :

The larvae measured 36·4 mm. The number of rays in all other fins except the ventral was the same as in the adults (D. 15. P. 15. V. 7. A. 19.). The snout was prominent and the maxillary extended behind as far as the gill opening as in the adult. Minute scales were present near the caudal region of the body. A brilliant silvery band was noticed from opposite the upper edge of the eye to the middle of the caudal fin. The young fish was identified as *Stolephorus indicus.*

The examination of the stomach contents of twenty-two of the juveniles reared in the laboratory showed that there was no change in diet except for the inclusion of diatoms such as *Cascinodiscus sp, Rhizosolenia sp,* and *Chaetoceros sp.* About forty-two juveniles measuring 35 mm.—43·2 mm. were collected from the sea. These resembled the adults closely except in size. They were found to have fed upon a wide range of planktonic organisms. 59·8% of the stomach contained copepods, 28·2% consisted of *Cladocera,* decapod larvae, veligers, *Sagitta,* echinoderm larvae and larval *Acetes.* The remaining 21% consisted of fish eggs and larvae whose specific identification could not be made due to the partial state of digestion.

Feeding habits of the adults:

A total number of eighty-three adult fishes were collected during the course of the investigation. The stomach contained copepods (*Paracalanus parvus, Oithona rigida, Euterpina sp* and *Temora sp*). Ostracoda, nauplii and larvae of cirripede as well as crustaceans such as *Penaeus sp, Lucifer sp,* and *Acetes sp* were also found. The diet consists exclusively of crustaceans and did not include fish larvae.

The post-larvae of this fish were collected in the month of March in surface hauls as well as in vertical hauls extending to a depth of ten fathoms. It is probable that this species inhabits the coastal waters, for not only the larvae and juveniles have been obtained from within eight miles of the coast, but large numbers of adults are landed throughout the year (Moses 1922).

Though copepods seem to be the favourite food of *Stolephorus indicus* during all the stages of its life history, there appears to be no specific preference for species of copepods. A similar observation has been made by Vijayaraghavan (1953) on *S.tri.*

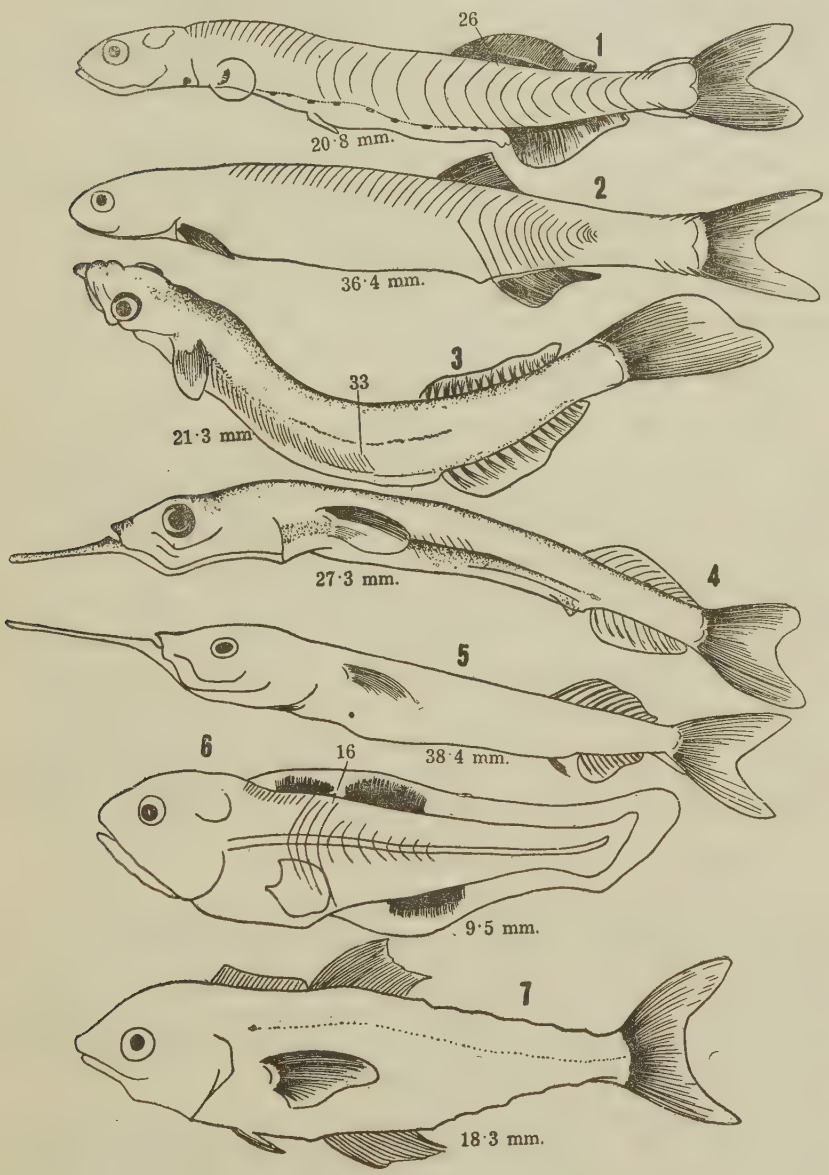
2. *The Food and feeding habits of Post-larvae, Juveniles, and adults of Hemiramphus Georgii Cuv & Val (Hemiramphus Cantori Day)*

The food and feeding habits of the half beak were studied by Jenkins (1936) in England, Roughley (1951) in Australia and Herre (1944) in the Philippines. We have no knowledge of the food and feeding habits of the marine species of *Hemiramphus.* Brief references to the food of fresh water and brackish water species of the genus and allied genera are found in papers published by Bhattacharya (1916), Devanesan (1937), Job and Jones (1938), Jones (1937), Chidambaram and Menon (1945), and Hornell ('23). Vijayaraghavan (1953) studied the complete life history and feeding habits of *Hemiramphus far* by collecting the eggs from the plankton and rearing them in the laboratory.

Fifty-nine advanced post-larvae measuring about 21·3 mm. were collected on 6th February, 1957 from the plankton. The long beak characteristic of the adult was indicated by a knob-like prominence on the lower jaw. The caudal fin had its full complement of rays though the pectorals had not. Eyes were very prominent and the operculum was much enlarged. Thirty-three preanal myotomes could be made out after fixing and clearing in cedar wood oil. Diffused greyish chromatophores occurred almost all over the body (Text-fig. 3).

Twenty-eight post-larvae were killed in order to examine their stomach contents and they appeared to have fed more on large planktonic animals such as *Lucifer, Acetes sp, Sagitta sp* and *Penaeus sp.* There were also young stages of *Sergestids sp,* megalopa and zoea of *Metapenaeus sp* and Brachyura, appendicularians and copepods (*Eucalanus sp, Acartia sp, Paracalanus sp* and *Oithona sp*). The remaining thirty-one post-larvae were reared in dishes kept in a cooled chamber.

Larvae 12th day after collection (*Text-fig.* 4):



Text-Figs. 1-7.

During the next twelve days the fish had grown to 27·3 mm. and the rostrum on the lower jaw had elongated to form 1/15 of

the body in length. Consequent on the elongation of the lower jaw, the head and the anterior region of the trunk became disproportionately large. There was however no change in pigmentation. The dorsal and anal fins resembled those in the adult fish in outline but were soft and transparent. All the features of the juveniles developed during the next eight days.

The larvae which were reared in the laboratory were fed with unsorted plankton and their feeding was observed under the binocular, by killing two or three larvae from time to time and examining the stomach contents. The diet continued to be the same till the 22nd day when the larvae started to take diatoms and filamentous algae in addition to the zooplankton.

Larvae 25th day after collection (Text-fig. 5):

The juvenile stage was reached on the 25th day after collection. The fish was identified as *Hemiramphus georgii.* The caudal fin was deeply forked with the lower lobe longer. Minute scales appeared on the posterior margin of the operculum. The number of rays in all the fins, except the pectoral, was the same as in the adult (D.16.V.6.A.15.C.16). The young fish was deep greenish blue in colour; a burnished silvery stripe was noticed along each side.

About five juveniles killed at this stage showed that they fed chiefly on copepods (*Euterpina sp, Acartia sp, Temora sp, Paracalanus parvus*), decapod larvae, larval cirripede, and ostracods as well as vegetable matter consisting chiefly of diatoms, such as *Coscinodiscus sp,* and larger algae such as *Cladomorpha* etc.

No change in feeding was noticed for another ten days.

About twenty-nine adults of 158·3 mm.—185·2 mm. in length, landed in Madras in May, were examined and 40·3% of their stomach contents was of sea weeds, 12·2% consisted of copepods (partly digested), 3·5% consisted of cirripede larvae, and copepod nauplii, 29·2% consisted of amphipods (Gammaridae), and the rest 14·8% was fully digested matter.

The frequent occurrence in large number of weed-clinging amphipods (Gammaridae) indicates that the adult fish have been browsing among the sea weeds. Roughley (loc.cit) had found that *Hemiramphus far* also fed chiefly on sea weeds. It should not be forgotten that the diet of the fish upto the 22nd day was purely carnivorous. All attempts to induce them to take diatoms failed during the early part of the post-larval stage.

Remarks:

Commenting on the Australian "Half beaks" Herre (1944) remarks that this fish frequents reefs and water of moderate depth for both breeding and feeding. During the few months, *Hemiramphus georgii* visits the in-shore waters of Madras, it prefers the rocky northern part of Madras shore rather than the sandy southern area. Further the sea weed and algae which formed nearly 50% of the adult diet are found attached to rocks and stones in Northern Madras. As suggested by Aflalo and Marston (1904) all the *Synentognathids* (the half-beaks, the gar fishes and the flying fishes) probably feed and breed in the shelter of rocks near the shore during the spawning season. The regularity with which the gar fish appears in the British and Welsh coasts for spawning is well known. While the different genera and species of these fishes are said to occur in large numbers in the coast of the above countries in Madras, the *Hemiramphus* is of minor commercial importance (Moses 1922) which is attributable to the great irregularity of their occurrence and paucity in number.

Hemiramphus georgii refused to feed on vegetable matter upto the 22nd day of their post-larval life, whereas Vijayaraghavan (1953) has recorded that the post-larvae of *H.far* started feeding on vegetable matter even from the 18th day. The juveniles of both the species fed mainly on copepods though vegetable matter also formed part of their diet. Regarding the diet of adults an analysis of the stomach contents of *H.georgii* showed a higher percentage of zooplankton than of vegetable matter while the diet of *H.far* consisted more of vegetable matter and less of zooplankton.

3. *The Food and Feeding Habits of Post-Larve, Juveniles and adults of Scomberomorus Lineolatus Cuv & Val*

The problem of the food and feeding habits of the European mackeral *Scomber scomber* has been thoroughly investigated by Allen (1897), Bullen (1908), Ehrenbaum (1923), Steven (1948), Sette (1950) and Matta Francesco (1956). The present author (1956) reported on the food and feeding habits of the Indian mackerel *Rastrelliger kanagurta* and has reviewed the previous work on all Indian mackerels. Recently Vijayaraghavan (1955) has reported on the life history of *S.guttatus* by collecting the various stages from the fishermen's nets. However it was considered worthwhile to report on the food and feeding habits of *Scomberomorus lineolatus* since the seer fish is a close relative of the Indian mackerel.

Only thirty-nine advanced post-larvae could be collected from the plankton. They had an average length of 9·5 mm. There were sixteen pre-anal myotomes and fifteen post-anal myotomes at this stage. The abdomen had become opaque due to the intensity of the brown pigmentation and the rest of the body was free from pigmentation. The end of the tail curved upwards and had a number of imperfectly defined rays as shown in Text-Fig. 6. All the fins were transparent. Fin-rays of the dorsal-fins and the anal-fin were found springing as soft rays on the dorsal and ventral margins of the body. Rays were also found making their appearance in the pectoral fin. Jaws were still toothless.

A few minutes after collection twenty-two larvae died. These post-larvae were found to have fed only on copepod adults and nauplii. The copepods were identified as *Paracalanus parvus, Oithona rigida, Oithona spinulosa, Oncaea conifera, Acartia erythraea, Temora* sp., *Pseudodiaptomus* sp. The remaining seventeen larvae were carefully reared till they developed the adult taxonomic features by giving them this diet.

Larvae 14th day after collection:

There was no change in these post-larvae except the growth in length. They measured 13·3 mm. The feeding also continued to be the same when observed under the binocular.

After about six days the post-larvae attained the juvenile stage (Text-Fig 7) and exhibited the adult taxonomic characters. The myotomes were no more visible. The mouth was large and slightly oblique and the lower jaw did not extend beyond the upper jaw. The pre-opercle was clearly seen but without the denticulation present in the adult. A straight lateral line was seen.

Sixty-eight juveniles ranging from 16·8-21·2 mm. were collected from the sea. The stomach contents of the juveniles measuring 16·8-18·2 mm. were filled with adult copepods and nauplii, cirripede larvae and ostracods. Whereas those of 19·2-21·2 mm. in length, probably because of their longer size were found to have fed on comparatively larger animals of the plankton such as *Acetes* sp., *Penaeus larvae* and adult copepods (*Temora* sp., *Oithona* sp., *Acartia* sp., and *Euterpina* sp.) as well as megalopa and zoea larvae.

A total of ninety-three adults 110 mm.-128 mm. in length were examined. Even though the amount of copepods (*Pontellopsis* sp., *Pseudodiaptomus* sp., *Paracalanus parvus, Temora* sp., *Eucalanus*

sp., and *Corycaeus* sp.) taken by the fish was much less than those taken by the post-larvae and the juveniles, they still formed this favourite food of the adults. *Penaeus carinatus* and Brachyuran zoea came next in preference. Other minor items of the diet were *Gammarus* sp., teleostean eggs Molluscan shells, Polychates and diatoms (*Asterionella* sp., *Trichodesmium* sp., *Coscinodiscus* sp., and *Nitzschia* sp.).

A comparison of the diet of the post-larvae, juveniles and adults of *Scomberomorus guttatus* (Vijayaraghavan, 1953) and of the present species showed a similarity in feeding.

Summary

1. The life histories of 3 species of Madras fishes, *Stolephorus indicus, Hemiramphus georgii* and *Scomberomorus lineolatus* have been studied from the post-larvae collected from the inshore plankton.

2. Charts of the food taken by the post-larvae juveniles and adults have been prepared at the end of each section.

3. The larval features distinctive of *Stolephorus indicus* as it develops into juveniles are described and the food chart shows that this species feeds mainly on copepods though no specific preference is indicated.

4. The adults of *Hemiramphus georgii* which live in the shallow rocky area feed mainly on vegetable matter available close to the coast. During the earlier post-larval stages when they live close to the surface of the sea farther from the coast, they refused to feed on vegetable matter and subsists on zooplankton for a period of 22 days. The gradual changes in both diet and habitat are commented.

5. The changes in the diet of the larvae, post-larvae of *Scomberomorus lineolatus* as they grow to the large-sized adults are related to sizes of the food organisms they consume. The small post-larvae start with copepod nauplii, the latter passing on to copepod adults and smaller pelagic organisms while the adults feed on larger planktonic and nectonic forms.

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Chart I showing the percentage composition of diet of Post larvae Juveniles and adults of *Stolephorus indicus*

Pecentage composition	Copepods	Acetes sp.	Squilla sp.	Lucifer sp.	Fish eggs and Larvae	Cladocert sp.	Decapod larvae	Veliger larvae	Sagitta sp.	echinoderm larvae	nauplii and larvae of cirripede	Ostracods	Penaeus sp.
Post larve ..	62·2	22·4	8·2	4·2	3·0	—	—	—	—	—	—	—	—
Juveniles ..	30·8	16·8	—	—	21·0	2·2	8·4	4·2	12·8	3·8	—	—	—
Adults ..	10·8	20·4	—	18·2	—	—	—	2·2	12·6	4·6	5·4	3·4	22·4

Chart II showing the Percentage composition of diet of Post-larvae Juveniles and adults of *Hemiramphus Georgii*

Percentage composition	Lucifer sp.	Acetes sp.	Squilla sp.	Penaeus sp.	Sergestids	Megalopa sp.	Zoea	appendiculavia	Copepods	Decapod larvae	Ostracods	Diatoms	Algae	amphipods	Sea weeds	cirripede larvae
Post larvae ..	10·8	9·2	20·8	20·2	10·4	8·2	10·4	4·2	5·8	—	—	—	—	—	—	—
Juveniles ..	—	—	—	—	—	—	—	—	22·6	12·4	22·2	13·8	10·2	—	—	18·8
Adults ..	—	—	—	—	4·0	—	—	—	12·2	—	—	8·0	8·8	20·9	40·3	5·8

Chart III showing the Percentage composition of diet of Post-larvae Juveniles and adults of *Scomberomorus lineolatus*

Percentage composition		copepods	copepod nauplii	Acetes sp.	Penaeus sp.	Megalopa sp.	Zoea	Veliger larvae	P. carinatus	bammarus sp.	Teleosteun eggs	Molluscan shells	Poly chaetes
Post larvae	..	78·2	21·8	—	—	—	—	—	—	—	—	—	—
Juveniles	..	50·8	—	12·8	18·2	5·2	6·8	6·2	—	—	—	—	—
Adults	..	20·2	—	—	—	—	2·8	—	10·8	20·2	10·0	18·2	17·8

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